OIL FUEL.

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OIL FUEL:

ITS SUPPLY, COMPOSITION, AND APPLICATION.

BY

EDWARD BUTLER, M.I.M.E.,

AUTHOR OF "CARBURETTORS, VAPORISERS, AND DISTRIBUTING VALVES,"
"INTERNAL COMBUSTION ENGINE DESIGN AND PRACTICE,"
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PREFACE TO FOURTH EDITION.

THIS book has come to be recognised as a standard text-book on the subject, and the demand for copies during the war was so constant that there was no opportunity for revision. Rather than again reprint without bringing up to date, the publishers have risked the book remaining out of print for eighteen months whilst the work has been thoroughly revised.

The importance of the subject is shown by the fact that already the Navies of the world are practically dependent on oil fuel; and for the mercantile marine, in the light of the miners' diminished output, there is significance in the growing tendency to abandon coal as the motive-power for the substitution of oil in fast-developing divergent lines, the steam-driven ship either turning to oil as furnace-fuel or to internal-combustion motors. Even in the space of a year the change over from coal to oil is remarkable, the number of oil-driven ships increasing from 2180 to 2950; and while the total number of ships in the world has only increased 9 per cent., oil-driven ships have increased by more than 35 per cent.

For a like reason, and partly owing to the increasing size of locomotives, oil fuel is also being more extensively used on the railways of the world. These and other applications bring liquid fuel, with its many advantages in transport, into such importance as to render necessary the closest study of its many applications.

ED. BUTLER.

December, 1920.

PREFACE.

In this treatise it has been the endeavour of the author to present to engineers, users, and others, an exhaustively and systematically classified record of the developments and progress made in the application of oil fuel for all steam-raising, metallurgical, and other purposes—except internal combustion engines—for which liquid fuel can be usefully employed.

The gradual evolution of the many forms of burners to their present state of efficiency; the various problems connected with the combustion of oil fuel in a furnace; the advantages, economic and mechanical, which accompany the use of fuel in a liquid form for different purposes—these subjects, as well as the vitally important one of supply, have all been dealt with in the light of the latest experience.

In so doing, Mr Sidney North's original work on *Oil Fuel*, as also useful information appearing in various technical publications, have been largely drawn upon, and the author's thanks are here tendered, and to the several firms who have kindly afforded information regarding their productions.

ED. BUTLER.

London, *May* 1914.

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OIL FUEL.

CHAPTER I.

ORIGIN, PRODUCTION, AND SOURCES OF SUPPLY.

LIQUID fuel for the most part is derived from crude mineral oil known as petroleum or rock-oil, of which there is evidence that at least some of its properties have for ages past been recognised both in the East and in the West, where, formerly known as fire-water in the district round the Caspian Sea and in certain parts of Mexico, and as medicine-water in Pennsylvania and other States of America, its uses were, as far as we know, mostly confined to ceremonial rites and to healing; but of its tremendous potentiality as a combustible and of its wide distribution there had been no conception, until after Drake's discovery in 1859 of a means for artificially increasing its production by drilling.

But, concerning the origin of petroleum—which, like coal, is composed of carbon and hydrogen in varying proportions—nothing definite is known; however, as its occurrence is more often than not associated with salt deposits, and is found either under extinct sea-beds, or at varying depths adjacent to, or even under, present sea-shores in widely distributed parts of the world, its origin must in some way be influenced by the action of salt water, either on vegetable or animal matter, or both; but obviously under circumstances of temperature, pressure, and time which would render anything approaching an exact demonstration of nature's process an impossibility. However, it has been demonstrated that liquid hydrocarbons, more or less identical in composition to petroleum, can be distilled from almost

any kind of organic matter, and in considerable quantity from shale deposits, from peat, lignite, and bituminous coal;[1] even from seaweed, for as much as 3 gallons of volatile oil plus 4 gallons of heavy oil have been distilled under suitable temperatures from a ton (dried) of this universally distributed substance, and bearing in mind that as this must have existed in immense quantities in the warm waters of the early geological period, would point to marine life and vegetation as the most probable origin of all mineral oil.

The geological conditions favouring the production and concentration of petroleum are termed *oil-sands*, which are really rock of a porous nature, as distinguished from strata of clay, gravel, granite, and other rocks, and when ground up by the *drill* has the appearance of sharp sand.[2] Oil-bearing sand strata are often found overlying a bed of salt, as in those of Tampico (Mexico), and at depths varying from 100 feet or so, as in some of the Pennsylvanian wells, down to several thousand feet, as in the Caspian fields and in those of California. The thickness of the oil-sands may vary from 5 to 50 feet or more; also the depth may vary considerably according to the anticlinal disposition of the oil-bearing strata, and in many extensive synclines is either beyond reach or found mixed or underlaid with brine.

The size and cost of an oil-well naturally depends on the depth it is found necessary to bore down to: those in the Californian fields, for instance, are often carried down to levels exceeding 2000 feet, or even 3000 feet, and are started large enough for the insertion of 15-inch or even 18-inch casings, these tapering down to 8-inch or 6-inch diameter at the bottom; while in Pennsylvania, with shallower wells seldom exceeding 600 feet in depth, it is only necessary to use a casing diameter varying from 8 to 6 inches, or even as small as 6 to 4 inches. Oil is found in the Mexican fields, and also in those of Borneo, at intermediate depths, seldom exceeding 1000 to 2000 feet; while in the Caspian fields[3] enormous casings are necessary owing to the loose nature of the ground, 18 inches or even 24 inches being

[1] W. R. Ormandy, D.Sc. [2] F. T. Ostrander.
[3] A. Beeby Thomson.

quite common, and as the average depth there is somewhere about 2000 feet, the weight of different-sized casing may, and often does, exceed 100 tons for a single well, which at £12 per ton meant a cost of over £1000 in pre-war days for casing only. The cost of drilling, however, is the greatest item, although not a serious matter for wells of a few hundred feet or so, these then usually averaging from £400 to £600 each; but in California, where wells are often bored down to levels 3000 to 4000 feet deep, and in a few instances even down to the 5000-feet level, the cost may increase to £10,000, or even £15,000, for a single well.[1]

Originally many oil-wells were dug by hand, and in Yenangyaung (Burmah) and Roumania have been carried down by this method to depths of 300–400 feet and even 500 feet under favourable circumstances, but naturally involves considerable danger from *caving-in* and lack of ventilation. The prevailing method everywhere now, needless to say, is to use some form of power-driven boring machine, of which there are several systems, but are mainly variants of either the percussion free-falling tool, or of the hydraulic rotary systems, a detailed description of which, together with that of the various methods used for raising petroleum to the surface from deep wells, are included in *Modern Pumping and Hydraulic Machinery*.[2]

One of the most important factors in connection with the use of liquid fuel is the supply available for the various purposes to which it is now being put. As time goes on this element will probably not play so important and controlling a part; but for the United Kingdom, having no proved oil deposits of much importance, except the shale oil of Scotland, and those recently discovered in Norfolk, the supply must always exercise a more than usually important influence on the matter of its employment. At first the chief source from which oil could be obtained was Caspiania and Pennsylvania, while it has also been obtained in smaller quantities from other countries. The oils obtained from the Baku and Maikop fields are more suitable for the production of that quality of residual which is adaptable to fuel purposes. During the last twenty years or so, however, several other large deposits

[1] Ostrander. [2] E. Butler: London, C. Griffin & Co., Ltd.

of heavy oil have been discovered in different parts of the world, which supplement, to a very important extent, the previous sources of supply. These discoveries have been made in Burmah, Siam, Java, the island of Borneo, and in Texas, California, Mexico, Peru, Algeria, and Egypt; and later in Nigeria, Trinidad, Venezuela, Cuba, and Persia; in Turkestan, Saghalien, Colombia, Papua, and quite recently in Mesopotamia in considerable promise; oil-bearing sands have also been found to exist in England and France, and a number of other parts of the world. Many of these have been more of the heavy oil class, providing a proportionately small amount of the volatile products, but yielding good supplies of lubricating oil and oil suitable for fuel purposes. In fact, since the discovery and development of the great Pennsylvanian fields no oil has been found of such a high grade—that is, capable of yielding so large a percentage of illuminating oil and motor-spirit.

It is a most difficult problem to estimate the stores of oil available in the various fields; for, unlike coal and other solid minerals, the only indication of the supply that one can obtain is the condition of the wells and the superficial area of the land which is believed to be oil-bearing. Naturally, this is a very rough and ready, not to say misleading, method of arriving at a decision as to the quantities available, and although attempts have been made to give figures representing the latter, it is quite impossible to rely on them. If the estimates[1] of the quantities of coal stored in the United Kingdom can only be accepted as slightly approximate, much more so must those referring to oil be held in doubt. The usual method of arriving at a figure in connection with oil supply is to take the area designated as oil-bearing, the number of wells it is possible to put down, and the average output that each well may be expected to yield. Anyone with the slightest acquaintance with the oil industry will recognise what a very unreliable method this is. It is certain, to begin with, that the whole area is not similarly productive, and that one well may produce and another may not, also that certain spots away from the anticlinal will not be productive at all. Therefore not only is it

[1] *Vide* p. 13.

impossible to estimate the quantity of oil that may be available or to say with any certainty that the available supply will last over any considerable length of time with the consumption increasing at the present rate; for whereas the total production in 1902 from all sources did not exceed a total output of 28 million tons, the output for 1909 had increased to nearly 43 million tons, representing an increase of nearly 60 per cent. in seven years, this production being obtained in countries distributed over a wide area, as will be gathered from the following:—

PRODUCTION OF OIL IN 1909.

Country.	Millions of Tons.	Country.	Millions of Tons.
United States	24	Canada	0·6
Russia	9	Mexico	0·35
Borneo and Java	1·7	Japan	0·25
Galicia	1·6	Peru	0·16
Roumania	1·1	Germany	0·15
Burmah	0·8	Other places	3
		Total supply	42·71

From which it will be seen that, next to the combined output of the U.S.A. oil-fields, including those of Calfornia, Texas, and Pennsylvania, Russia then ranked second in importance with its new Maikop oil-fields, in addition to those bordering on the Caspian Sea. In regard to the latter, the principal drawback is their geographical position, which, however, might be greatly improved by providing more reliable facilities for the transport of the oil to the seaboard of the Black Sea. The 8-inch pipe line, which was not completed until 1905, and at first only used for the transport of refined illuminating oil, is not only wasteful, but costly to work and maintain, on account of the number of relay stations required. The cost of conveying oil along the 600 miles separating Baku from Batoum was then reduced to 15s. per ton, thus raising the price of oil from 20s. to 35s. per ton, and considered high, but is much less significant with the present prices of liquid fuel. The production of fuel oil in Russia in 1913 amounted to nearly 10 million tons, of which output the greater proportion was consumed in the country itself, the bulk, of course, on the various railways. The quantity exported is but a small proportion of the quantity produced, the remainder

being retained for the Caspian Sea vessels and for industrial purposes. Thus it will be seen that Russia did not then help the liquid-fuel trade in foreign countries to any great extent, and now still less.

The next supply to enter into competition is derived from the island of Borneo, and is obtained from fields owned and developed by the Shell Transport and Trading Co. The oil raised here produces, besides fuel oil suitable for steam raising and for large power oil-engines, a considerable percentage of light oil suitable for automobile and other motors. A large quantity of this is brought into this country and disposed of for use in metallurgical work and for power purposes. But, as to the extent of the supply in the East Indian fields, this is as unknown as that in Persia, Roumania, Mexico, or in California, and a number of other countries. However, the Borneo fields have been tested over an immense area, wells having been put down as much as sixty miles apart at points running longitudinally, and the same description of oil in large quantities has been found. Borneo oil is limpid, contains but little solid residuum, and yields about 25 per cent. of illuminating oil and motor-spirit, plus 60 per cent. of fuel oil. The output for 1918 was close on one million tons.

The Texas fields are of a very different nature from those of Russia and Borneo, in that the wells put down have turned out to be nearly all gushers of a very high producing power in the first instance. Certainly, this field has proved to be more of a temporary producer than any of its contemporaries. In Borneo, Burmah, California, Oklahoma, and Mexico, for instance, the wells have been much more moderate in their manner of yielding the oil, although it should be mentioned that in 1908 the Dos Bocas well in Tampico commenced to spout from a depth of 1800 feet, and continued for seven weeks at the rate of approximately 20,000 tons per day—which yield was for the most part unfortunately lost by fire before the pressure became exhausted; while in Russia, although most prolific spouters have been common, these have been spread over a wider area, and have not had the appearance of being fed from the same source. This is an important feature in the case, because it affects the exhaustibility of the supply one way

or the other. When the Texas wells began to yield, the output amounted to as much as 1500 tons a day per well, some even exceeding this figure; after a few months, however, the gas-pressure greatly diminished, and the daily output was, of course, substantially reduced, and three and a half years after the bringing in of the field, the yield of the wells was not more than 15 tons per well per day, and is now less than forty million barrels per year, this diminished supply having to be raised by means of pumping. America has ample scope and possibilities of consuming all that her several fields can yield, and there is thus more reason for oil to affect the position of coal in certain districts in that country than of its doing so as an imported commodity in this. Other fields, however, are being opened up in Texas which may supplement the deposits of the Beaumont field.

As regards the Californian supplies and their relation to the liquid-fuel question, this oil is admirably suited for fuel purposes, but being comparatively turbid, contains a high percentage of solid residuum, and very little of the light oil series; there is, however, a plentiful and regular supply. At the present time the most of the available supply is consumed in California itself, chiefly on the railways and by the various coastal steamers; this oil is also extensively used in various industrial establishments in and around San Francisco; thus the Californian supply does not affect the Eastern markets to a material extent.

The Pennsylvanian fields constituted for many years the principal supply obtained in U.S.A., and as far back as 1872 this State produced at the rate of 20,000 barrels per day, equal to approximately 7,000,000 barrels in the year, which rate has been maintained and in some years exceeded ever since, as shown in the table below:—

Year.	Barrels.
1909	10,434,000
1910	9,848,000
1911	9,201,000
1912	8,712,000
1913	8,865,000
1914	9,109,000
1915	8,726,000
1916	8,466,000
1917	7,733,000
1918	7,408,000

The value, however, of this supply has considerably appreciated, for whereas in the early years, what with limited demand, difficulties of transport, and rate competition, the price had been known to fall to a few cents per barrel, and in 1915 was only $1.35, in 1918 the price had advanced to $4.25, and is now nearly $5 per barrel, despite the enormously increased production in other fields in U.S.A. and other parts of the world, showing for U.S.A. alone a production equal to a million barrels per day, which, as the world's present total output is 500 million barrels per year, is equal to over 70 per cent. and in 1912 was 75. But the most significant factor is the increasing consumption, the demand for oil now in U.S.A. actually outstripping the supply, so much that in 1919 nearly 60 million barrels of crude was imported from Mexico. According to the U.S.A. Geological Survey, American consumption has nearly doubled since 1911, in which year the supply was equal to the demand, as shown in the table below:—

Year.	Consumption.	Actual Production.	Marketed Production.	Imports.
1919	406,000,000	354,000,000	370,000,000	53,000,000
1917	376,000,000	328,000,000	348,000,000	28,000,000
1915	296,000,000	305,000,000	280,000,000	16,000,000
1913	260,000,000	250,000,000	250,000,000	10,000,000
1911	225,000,000	229,000,000	225,000,000	...

The following table shows the production from the several principal fields in 1918:—

	Barrels.
Oklahoma	103,300,000
California	97,500,000
Kansas	45,400,000
Texas	38,700,000
Louisiana	16,000,000
Illinois	13,300,000
Wyoming-Montana	12,600,000
West Virginia	7,800,000
Pennsylvania	7,400,000
Ohio	7,300,000
Kentucky	4,400,000
Indiana	870,000
New York	800,000
Colorado	140,000
Other States	410,000
Total	355,920,000

According to another authority the production from California in 1918 was 102,640,000, and in 1919, 101,907,000 barrels; and the total annual production from all countries for the "last ten" years was as follows:—

In 1908	it amounted	to	178·5	million barrels.
,, 1915	,,	,,	281	,,
,, 1916	,,	,,	300	,,
,, 1917	,,	,,	335	,,
,, 1918	,,	,,	349	,,
,, 1919	,,	,,	366	,,

Ranking next in importance, as far as present indications show, are the extensive oil-fields of Mexico, the most productive of which are the Juàn Casiano, Los Nuranjos, Tepetate Chinampa, and Chijoles, where more than 800 wells have been drilled, 300 of which are still in profitable production, plus an additional 90 in which the pressure is exhausted, the remaining 420 having been closed down either for lack of pressure or from being water-logged. There are besides this 120 in course of drilling, plus another 140 located, the present output, as shown below, equalling one-sixth of the world's supply:—

TOTAL PRODUCTION OF CRUDE OIL IN MEXICO.

Year.	Barrels.
1910	3,333,000
1911	14,080,100
1912	16,560,000
1913	25,700,000
1914	26,240,000
1915	33,000,000
1916	40,400,000
1917	56,000,000
1918	64 000,000
1919	87,000,000
1920	120,000,000[1]

Although the total production of Russia in 1913 was equal to one-third of the world's supply, it is now less than one-eighth, and as many of the wells there are water-logged and mostly dependent on pumping, the importance of Caspiania for the world's future may be neglected, as more than the total output will be required for the interior.

[1] Estimated.

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[1] Estimated.

Oil Springs, where the first Canadian crude was struck 60 years or more ago, and which has been producing from the deeper formation since about 1881, has an increase of 573 barrels, and Bothwell, after 25 years of production, has slightly increased its production. The lower horizons of the corniferous limestone in these fields, with their slow but steady yield, favour a sustained production, and this tendency has been helped by the efficient management of men especially trained in the business. The efficient handling in these fields makes even small wells profitable. In addition to the Ontario crude production of 220,100 barrels, there was a nominal production in Albert county, New Brunswick, of approximately 3000 barrels. This oil is chiefly secured by drips from the gas wells in that field, and is used locally. In Western Canada the only commercial production is from the small Okotoks pool southwest of Calgary, where the refined output for the year amounted to 14,171 barrels, compared with 15,526 barrels in 1918. There are no official figures of the crude oil production, but unofficial figures place it at 14,638 barrels, the proportion of residuals after extracting the lighter constituents being decidedly small. These figures give a total production of crude oil in Canada for 1919 of 237,271 barrels, compared with 304,295 barrels in 1918.

The yield from the shale deposits in Scotland has averaged since 1910 about half a million barrels per year, but this will soon be supplemented by oil obtained from rich deposits in Norfolk which are being worked on an extensive scale. Prospecting for oil-bearing sands is also being systematically proceeded with; 11 sites have been selected, and from 3 boreholes sunk in Derbyshire down to the 3000-feet level, and other 5 down to the 2000-feet level, oil has been struck. Trial bores have also been sunk in Staffordshire and Midlothian. In France, too, oil-bearing sands and shale have been located, but with the enormous consumption in both these countries, the home supply in any case will not materially affect the demand for imported motor-spirit and oil fuel now used for so many purposes. The more volatile constituents are a factor of vast importance compared with the conditions obtaining only a decade ago, to instance which it is only necessary to state

that, whereas in 1903 the volume of motor-spirit consumed in Great Britain (principally for power purposes) amounted to less than 10 million gallons, the consumption of motor-spirit in this country alone had in 1910 increased to nearly 50 million gallons, or, in other words, to 167 thousand tons; and while in 1914 this had attained to the enormous amount of 90 million gallons, most of which was used in connection with the automobile, aero, and other high-speed motor industries, the quantity of motor-spirit imported into this country in 1919 had again more than doubled, and for 1920 will, it is estimated, be 250,000 million gallons.

Apropos the world's present annual production of crude petroleum, amounting to upwards of 75 million tons, of which from 40 to 80 per cent. is suitable for fuel oil, it may be interesting to compare the world's production of coal, which (in order to keep pace with the progressive demand for heating, blast furnaces, gas works, and for motive power) has risen from an annual consumption of 15 million tons, as estimated for the early part of the nineteenth century, to the enormous consumption of 1200 million tons; of which amount 500 million tons is produced in the United States, 300 millions in Great Britain, 120 in Germany, 70 in France, 30 in Belgium, and 180 millions in Australia, Canada, India, and other countries. Even at this rate of exhaustion it is estimated that the world's supply is sufficient for at least 500 years. In the light of these figures a total production of liquid fuel of 75 million tons may not at first sight appear to be of such importance as when considered from the point of view of its bearing on power application only. But it must be borne in mind that less than one-third of the coal annually consumed is used for the purposes of motive power, as against three-fourths of the petroleum produced, from which it will be seen that the actual comparison, weight for weight, between the quantity of liquid fuel used for power purposes and that of fuel in its solid form is as 56 million tons to 400, *i.e.* 14 per cent.; which comparison, when the respective heating values of the two fuels are taken into consideration, should read as 84 millions to 400 millions of tons, *i.e.* the total power now produced by means of liquid fuel has already attained to the significant proportion of over 21

per cent. of the total power produced from coal. And, recognising that the first oil-well was sunk by Drake as recently as 1859, and that it is only within the last few years that the surprisingly extensive distribution of oil has been brought to light, it would be hazardous indeed to form any but an approximate estimate what position liquid fuel will occupy in the world's economics in another decade.

In regard to future prospects for a continuance of the world's supply of petroleum to meet the increasing demand for liquid fuel:—According to statements made by eminent authorities, including Dr David Day, Dr Engler, Prof. Vivian Lewes, and Sir Boverton Redwood, the world's available store of petroleum will have become so depleted towards the end of the present century that long before then other sources of supply will have become necessary. Also, on the authority of the United States Geological Survey, the reserves estimated to be in the ground in 1918 were 6750 million tons, which is equal to about 100 years' supply; but the most that can be said for this is that it is mere conjecture; for notwithstanding that, certain oil-fields, notably those in Pennsylvania, Caspiania, and Canada, have shown a decided falling-off in output, also that it is more the rule than the exception for individual wells to have a short life; this is forcibly exemplified by the U.S.A. Geological Survey Report below:—

Year.	Holes drilled.	Now Producing.	Dry Holes.	Producing Gas only.
1915	13,600	8,740	2860	2000
1916	20,540	15,800	4000	1740
1917	23,070	16,430	4700	1940
1918	25,550	17,850	5700	2000

Despite the short life, however, of an average well and the cost of drilling, it is an undoubted fact that the world's production of oil is steadily increasing, although not so fast as the demand, and, as shown below, had advanced from a total output of 30 million tons in 1903 to 50 million tons during the succeeding ten years, when the outputs of the

several oil-producing districts were proportioned according to the following table:—

PRODUCTION OF OIL IN 1913.

Country or State.	Tons.
California	12,000,000
Russia	9,800,000
Kansas and Oklahoma	8,000,000
Pennsylvania, Virginia, Ohio, Indiana, and Kentucky	4,000,000
Texas and Louisiana	3,000,000
Illinois	2,500,000
Mexico	2,300,000
Galicia	1,800,000
Borneo, Sumatra, and Java	[illegible]
Other States of U.S.A.	1,500,000
Roumania	1,400,000
Burmah	1,000,000
Scotland	360,000
Japan	260,000
Peru	180,000
Germany	150,000
Canada	43,000
Trinidad	41,000
Assam	15,000
Australasia, North and South Africa	8,000
Italy	7,000
Hungary	3,000
	49,967,000

In comparing the production for 1913 with that of 1909, we find that the total U.S.A. output had advanced from 24 to 31 millions of tons; that the yield from the Russian fields had remained practically stationary; as also that of Burmah, Borneo, Japan, Peru, and Germany; that the output from Mexico has shown an advance from 0·35 to 2·3 millions of tons, and that of Galicia from 1·6 to 1·8; Roumania from 1·1 to 1·4, and Trinidad from a negligible quantity to 0·04; that the principal country then showing a lessened output was Canada; also that the country possessing the most promising field outside of the United States was Mexico.

Much as was the increase in the world's supply during the period 1909–1913, the demand for oil fuel during the period of the war had become so insistent, that the output from most of the known fields has been considerably increased and some of them enormously. How long this will continue there is no definite indication, but what with

many of the oil-bearing districts being so extensive, and with new sources continually being discovered, the world's supply will in all probability continue for at least several decades even at a higher rate of production than now.

WORLD'S PRODUCTION OF PETROLEUM, 1914–1918.

Country.	1914. Barrels.	Percentage of Total.	1918. Barrels.	Percentage of Total.
United States	265,762,000	66	355,930,000	69·25
Mexico	21,188,000	5	63,830,000	12·40
Russia	67,000,000	16	40,000,000	7·80
Dutch East Indies	12,705,000	3·1	13,285,000	2·58
India, Burmah	8,200,000	2	8,700,000	1·60
Persia	1,000,000	·2	6,500,000	1·25
Galicia	5,035,000	1·2	5,000,000	1·00
Japan, Formosa	2,738,000	·68	2,500,000	·47
Roumania	12,826,000	3·2	8,730,000	1·70
Peru	1,917,000	·48	2,530,000	·49
Trinidad	643,500	·16	2,082,000	·42
Egypt	777,000	·19	2,000,000	·40
Argentina	400,000	·09	1,320,000	·26
Germany	999,000	·25	700,000	·13
Canada	214,800	·05	308,000	·07
Venezuela	50,000	·01	190,000	·04
Italy	39,500	·015	35,000	·010
Cuba	5,300	·002	20,000	·066
Other Countries	50,000	...	100,000	·025
Total	401,600,000	...	514,760,000	...

But with an increasing demand for liquid fuel of all grades, other sources of supply are being developed; for instance, the annual production of tar oil—which can be successfully used for all furnace work, and for steam raising with either steam- or compressed air-jet burners, and also in high compression air-injection oil-engines—already exceeds 2 million tons, obtained as a by-product from gas works and coke ovens, the average yield being 6 to 8 per cent.; if, therefore, for instance, one-third of Great Britain's annual output of 300 million tons of coal were coked, on one of the low temperature systems, this alone would produce somewhere near 5 million tons of tar oil, which could be used as a substitute for petroleum fuel oil. Then, again,

under modified conditions regulating the quality of illuminating gas, under which gas would be estimated for its calorific value as against its illuminating power, the gas of Great Britain alone would yield about 30 million gallons of benzole, and, similarly, from 2 to 3 gallons of this light oil can be distilled from 1 ton of tar oil, as produced under ordinary gas works' temperature conditions. From which it will be gathered that, what with the vast tracts of undeveloped petroliferous territory in various parts of the world and improved methods of producing liquid fuel from our immense coal resources, there need be no fear of a scarcity in the supply for many years to come.

TABLE SHOWING THE TOTAL OUTPUT OF THE SEVERAL OIL-PRODUCING COUNTRIES DURING THE LAST SIXTY YEARS.

	Barrels.	Percentage of Total.
United States . .	4,608,572,000	61·42
Mexico	285,182,000	3·80
Russia	1,873,039,000	24·96
Dutch East Indies . .	188,389,000	2·51
Roumania	151,408,000	2·02
India	106,152,000	1·41
Persia	14,056,000	0·19
Galicia	154,051,000	2·05
Peru	24,414,000	·33
Japan and Formosa .	38,498,000	·51
Trinidad	7,432,000	·10
Egypt	4,848,000	·07
Argentina	4,296,000	·06
Germany	16,664,000	·22
Canada	24,424,000	·33
Venezuela	317,000	·02
Italy	974,000	
Cuba	19,000	
Other Countries . .	397,000	
Total . .	7.503,147,200	100·00

CHAPTER II.

THE ECONOMIC ASPECT AND HEAT VALUE OF LIQUID FUEL.

THE advocates of liquid fuel, as compared with solid fuel, were wont to find themselves in a somewhat anomalous position, as they had to maintain the great economic advantages of petroleum for fuel in the face of a prohibitive price. The two points are entirely distinct, but in this age of money values a commodity has to be cheap to be regarded as offering economic advantages. The compensations, however, offered by liquid fuel are so many that a high price can be allowed, provided, of course, that, when all the former are taken into consideration, there is no excess of actual money cost against it. Coal is, under any conditions, a dirty, wasteful, and variable means of raising steam and providing power. Its quality varies so enormously that its wastefulness is not always appreciated to its full extent. There are a number of constituents which are not at all necessary to the provision of heat; they are injurious to boilers and furnaces, and harmful to individuals working with them. Coal is increasingly difficult to mine, and comparatively costly to handle, the labour of removing the refuse from burnt coal being almost as great as feeding the fire itself. The vast difference between liquid fuel and coal is no more graphically seen than in the bunkering of a vessel with coal, and loading her up with oil. It is typical of the two descriptions of fuel—the one the embodiment of clumsiness and uncleanliness, the other of ease and efficiency. Coal has maintained its position as chief power-provider for so long because the greatest steam-using countries have vast stores of this mineral, and because

national expediency and welfare come above every other consideration in industrial life. Then, too, the appliances which are used for heating and power purposes have all been fitted for the use of the solid fuel, and to discard old and familiar customs is not an easy process in any country. Even America has not yet been able to materially change the methods instituted at the beginning of its industrial existence. With such a vital thing as fuel—the basis of all trade, industry, and commerce—this change must necessarily be slow, though it need not be conservative. It must not be forgotten, however, that, whatever drawbacks coal possesses as a fuel, the large deposits still available in the foremost industrial countries of the world are not at all likely to be neglected on account of the advantages of liquid fuel: not one mine will be shut down because liquid fuel has displaced the solid product, and not a single miner is likely to be deprived of his living on this account. Petroleum is the great supplementary fuel supply for coal, just as electricity has supplemented coal gas for lighting, and steam for power purposes. Yet there has been no falling off in the use of coal for either of these purposes; rather has it increased the consumption by giving an impetus to the two branches of industry.

In regard to the use of coal for raising steam, it does not seem possible that engineers have reached the end of their resources in improving the means by which the heating power of coal is utilised. The full efficiency of coal has never yet been obtained, and if methods and appliances were introduced, greatly increasing this heating efficiency, it would undoubtedly give coal a longer life. This argument is also applicable to liquid fuel, the use of which has not yet been thoroughly mastered. Burners are not as efficient as they will be eventually, and the conditions under which oil fuel should be burnt are not yet thoroughly perfected; oil-firing is therefore not as economical as it might be. Oil fuel itself is a much more delicate combustible to handle than coal; it is more sensitive to external conditions, and therefore requires a considerable amount of scientific investigation to enable the ordinary man to be put in possession of facts and principles necessary to get the best and surest work out of it.

Nevertheless, even at the present stage of the use of oil fuel, petroleum has certain distinct economic advantages over coal. As has already been mentioned, the method of obtaining oil fuel is much simpler and less costly than that of coal; very little refining is necessary other than distilling off the benzine and kerosene constituents. When obtained, the ease and cheapness with which it can be shipped and transported are in very favourable comparison with the methods necessary for coal.

In its application still more significant economies come to light, especially on steamships, mercantile and naval. Although in the locomotive the scope for economy is more limited and less noticeable, chief among the advantages there being the easier control of oil fuel to the furnace and the more constant speed obtainable from the liquid combustible. Liquid fuel also affords greater facility in responding to increased loads, which is, of course, an important item in connection with railway traffic, where the loads are so variable. Refueling, again, is a consideration equally apparent in locomotives as in steamships, though the quantities are not so large; for instance, a main-line express engine can take in 600 gallons of liquid fuel in from four to five minutes—a wonderful saving in time compared with coal.

On steamships the extent of the economy is greatly emphasised, as the requirements are on a much more extended scale. Even to the most superficial the advantages of oil fuel on board ship are shown in a favourable light. In bunkering with coal, everything on the vessel is made grimy with dust, and necessitates considerable labour in cleaning up again. What a different aspect does a vessel using oil fuel present! The ship is as clean as before loading up; little or no labour is required in the process, as the oil can either be run from the storage tanks on shore by means of gravity, or it can be pumped in from barges or the tank steamer; liquid fuel can also be stored away in the ballast tanks, the oil as it is drawn off being replaced by water. In a merchant ship this means more space available for cargo, and in a warship it means greater fighting room, more boiler space, and, seeing that a greater amount of power is stored in oil, weight for weight, than coal, a much wider range is given to the vessel, the range

of action thus being increased by 50 per cent. on the bunker weight and 90 per cent. upon the bunker space allotted, when oil is used. Thirty-six cubic feet of oil are equivalent to 67 cubic feet of coal, and in the matter of weight 2 tons of oil are equal to at least 3 tons of coal. These are undoubted economic advantages, and are of vital importance to a battleship.

Another economic advantage of oil fuel in both merchant- and war-ships is the small number of firemen necessary to attend to the furnaces. The question of stoking on ships has always been a difficult one, but liquid fuel reduces the difficulties to a minimum. In certain cases the stokehold staff has been reduced from thirty-two to eight when using oil, and not only is this economy effected, but the difficulty in maintaining full-power speed, due to the trimming and stoking not being done to the fullest capacity of the boilers, and also in some from clinkering of the furnace grates, is entirely overcome. This is an advantage which must strongly appeal to all shipowners. Uniformity of steaming is synonymous with economy and augmented profits.

For naval purposes the smokelessness of liquid fuel is also one of its favourable features, and with proper combustion this can always be obtained. Considering also that the chemical composition of coal and petroleum fuels (dealt with in another chapter) is practically identical, the smokelessness of the latter proves it to be more capable of perfect combustion than coal, and therefore far more economical; for, as everyone knows, in spite of the decades that have passed since steam power came into use, no furnace has ever yet been constructed that is capable of producing perfect combustion from coal under the conditions obtaining at sea, and even with smokeless combustion it does not follow that the highest boiler efficiency is obtained when using coal, as this necessitates a surplusage of air, the cooling effect of which more than neutralises the effect of the more perfect combustion. Indeed, the difference of efficiency of an oil-fired over a coal-fired furnace is due to the ability for more perfect regulation of the air supply; thus the difference in heat effect is actually greater than the theoretical difference in the calorific values of the two fuels.

Efficiencies as high as 84·5 per cent. have been obtained in this country on Scotch marine type boilers, using Mexican fuel oil with the pressure system of oil burning.

At a large London factory which converted their Lancashire boilers from coal to fuel-oil firing, the water evaporation per lb. of coal, having a calorific value of 11,451 B.T.U., was 7·22, whereas when working with the pressure system of oil burning, using an oil having a calorific value of 18,750, the evaporation per lb. of oil reached 14·44 lbs. The quantity of water evaporated per square foot of heating surface on coal was 3·3 lbs., whereas on oil showed over 7 lbs., thereby increasing the boiler rating by over 100 per cent.

The following test results with topped Mexican crude and ordinary steam coal on a factory boiler, under everyday working conditions, are instructive, although showing no particular efficiency on either fuel.

FUEL OIL.

Fuel oil—	
Specific gravity at 60° F.	·953
Viscosity at 100° F. (Red. No. 1)	2·130 secs.
Flash point (close)	160° F. (above)
Calorific value	18,430
Water evaporated—	
Lbs. of water per lb. of oil	12·15
Lbs. of water per lb. of oil (from and at 212° F.)	14·38
Boiler efficiency	73·37 per cent.

COAL.

Coal—	
Calorific value in B.T.U.	14,432
Water evaporated—	
Lbs. of water per lb. of coal	7·76
Lbs. of water per lb. of coal (from and at 212° F.)	9·31
Boiler efficiency	62·28 per cent.

Rebunkering at sea with solid fuel has always been difficult, but with a liquid fuel this drawback disappears. So easily can the supply be transferred from one vessel to another, that a length of tubing will do the work of fifty men, and 300 tons be shipped in the short space of one hour. The value of this facility is so apparent in the case of a warship requiring to be rebunkered away from port

that it needs no emphasis, while the saving in time, labour, and fuel is equally apparent.

There are other economies in the substitution of liquid for solid fuel. Although there is some difference of opinion in regard to the wear of the boiler plates, etc., the general consensus of opinion is that liquid fuel is much less injurious to the boilers and furnaces than coal, owing to the maintenance of a more equable temperature in the furnace, and to the possibility of steaming for long periods without having to open the fire doors.

In the matter of actual fuel economy, early experience in the steaming of Shell liners may be stated briefly here, as these pioneer vessels have burned liquid fuel for longer periods continuously than any other ships with reference to which data are obtainable. The consumption of oil on S.S. *Clam*, for instance, over a period of two years, during which time she traversed 89,000 miles, amounted to 18 tons per day; whereas with coal the consumption amounted to 26 to 28 tons per day. The *Murex*, another tanker, consumed 25 tons of coal per day, but after being converted to an oil-burner her consumption was reduced to 16 tons. The *Strombus* again, another Shell liner, burned 43 tons of coal, and subsequently 30 tons of oil per diem; these and other ships have for years steamed direct from Singapore to the Thames *viâ* the Cape, a distance, be it noted, equal to 11,800 miles, without rebunkering, which is a performance, it is unnecessary to add, that would be quite impossible with coal.

As another instance S.S. *Conch* may be cited, this cargo boat of 7700 tons carrying capacity, formerly averaged a consumption of 31 to 33 tons per day, and a speed of 9·5 to 10 knots, with coal-firing, but on being converted to oil-firing on the pressure jet system, averaged a speed of 10 to 11 knots, and on a reduced consumption of 22·5 tons per day, or resulted in a mean saving of 33 per cent.; besides which, this ship was then able to carry 150 to 200 tons more cargo.[1]

An important factor with oil-firing, and one not perhaps sufficiently realised, is the advantage of being able to dispense with the cleaning of the furnace grates, and also

[1] *The Marine Engineer and Naval Architect.*

to the fact that full steam pressure can be continuously maintained, which remark applies more particularly to the tropics, where considerable difficulty is often experienced in keeping up a full head of steam with a temperature in the stokehold varying from perhaps 110° to as high as 125° F. Further, there is the advantage in oil-firing of showing better results as regards speed in relation to consumption and upkeep of boilers; also, in that the complete firing installation, including oil-pumps, heaters, filters, etc., can be directly controlled by the engineer on watch, while 1 fireman can attend to 12–18 furnaces; in effect the collective advantages are such that now with the greater proportionate advance in the price of coal, cargo and general service steamers are being converted from coal to oil-firing as fast as the necessary apparatus can be installed.

To large and fast ocean liners the use of liquid fuel in place of coal compares to even better advantage, as the result not only of the greater convenience and facility of bunkering, but to the difficulty of getting the fuel brought forward to the boiler furnaces quick enough to keep up the pace when using coal, in consequence of which a further great reduction in the stokehold staff is possible. In emphasis of this, the case of a transatlantic liner of the *Aquitania* class may be instanced, where the number of firemen carried was 312, whereas now, with oil-firing, the number of firemen[1] is reduced to 54, which advantage, however great to a ship of the mercantile marine class, is of far higher significance when applied to a warship.

It is, however, with the more general use of the internal combustion engine for large powers that the significance of petroleum will tell, especially for marine propulsion. For with internal combustion engines, not only is the arduous work of stoking dispensed with (as already made possible by the perfection of means for the combustion of oil fuel in boiler furnaces), but the boilers themselves, the space thus occupied being then available for power, or cargo-carrying purposes. The reduced consumption made possible is, however, the most important factor, as the

[1] This allows for 18 men per shift to attend to the burners, pumps, filtering and heating apparatus for 168 furnaces.

advantage of liquid fuel as now obtained by furnace combustion, *e.g.* a minimum of 1 ton equalling 1½ tons of good coal, is then raised to a scale in which 1 ton of oil is the equivalent of 3 tons of coal when used under the most perfected conditions, and to even 5 tons for ships of less than 500 i.h.p., *e.g.* the *Vulcanus*, the first ship of this size to be fitted with an internal combustion engine (450 b.h.p.), consumes two tons of gas oil per day; whereas an almost identical ship, the S.S. *Sabine*, and also of 2100 tons carrying capacity, consumed 11 tons of coal per day, the speed of both ships averaging 8 knots. As a result of the fuel economy obtained in this pioneer boat and in hundreds since, shipbuilders are now installing oil engines in place of steam for the smaller boats.

Internal combustion engines[1] using either liquid or gaseous fuel are already established on a permanent basis for practically all purposes requiring powers not exceeding 100 h.p. or so, and are fast competing with steam for the larger powers despite more perfect means for generating power by furnace combustion; it is therefore quite inevitable that any such improvement can but have the effect of deferring to a more distant day the ultimate triumph of oil over steam for maritime propulsion, and for many other purposes, by reason of the vastly superior economy obtainable over the most perfect form of engine depending on furnace combustion.

[1] These are fully described for all purposes and their limitations for marine propulsion pointed out in *Internal Combustion Engine Design and Practice.* London, C. Griffin & Co., Ltd.

[TABLE.

Calorific Value of Liquid Fuels.

Description.	Specific Gravity.	Carb.	Hyd.	Sulph.	B.T.U.	
1. Oil used at trial of torpedo-destroyer	0·921	85·28	11·93	0·56	17,975	
2. Ordinary fuel oil	0·888	86·20	12·57	0·31	18,175	
3. Fuel oil as used for Diesel engines	0·923	..	..	0·45	17,921	
4. "Light fuel oil"	0·900	85·58	10·81	0·43	18,205	
5. "Admiralty fuel oil"	0·928	86·40	11·55	0·84	17,930	
6. "Residuum"	0·943	86·44	11·23	0·30	18,117	
7. "Black oil"	0·928	86·44	11·[illegible]	[illegible]·51	1[illegible]959	
8. Semi-refined oil (specially adapted for Diesel engines)	0·904	85·05	12·15	0·37	17,996	As determined in a Mahler bomb calorimeter by Prof. Patterson.
9. Crude Roumanian	0·825	..	..	0·20	17,863	
10. " "	0·830	83·77	12·98	0·29	18,022	
11. Solar oil (Texas)	0·862	85·35	12·92	0·17	18,344	
12. Scotch shale oil	0·855	86·16	12·37	0·26	18,248	
13. " " "	0·862	85·35	12·44	0·29	18,817	
14. " " " (works well with Diesel engines)	0·867	..	..	0·33	17,980	
15. Coal tar oil	0·958	86·16	9·05	0·30	16,960	
16. Gas oil (gives trouble with Diesel engines)	1·067	87·62	5·98	0·67	16,153	
17. Gas oil	1·004	83·72	7·29	0·82	15,977	
18. Scotch Pumpherston fuel oil	0·868	..	..	..	18,770	(Net) Barr.
19. Californian fuel oil	0·94–96	..	..	..	18,550	(Net) Cory.
20. Russian astatki	0·93	..	.	..	18,600	(Net) Urquhart.
21. Beaumont oil	0·924	..		..	19,000	Richardson.
22. Borneo	0·960	..	..	..	18,830	Orde.
23. Burmah	0·850	..	..	..	18,800	
24. Mexican crude	0·942	82·7	11	3·35	19,000	
25. Kerosene	0·780–825	..	..	..	19,000	Mahler.
"	0·750–860	85	11·5	..	21,000	Ormandy.
"	0·750–860	..	..	..	21,000–22,000	Friday.
26. Petrol	0·690–730	..	..	..	20,000–21,000	Ormandy.
"	0·730–740	84	16	..	20,800	"
Gasolene	0·660–070	..	..	..	18,000	Friday.
27. Benzole	0·820	..	..	..	18,500	
" 90 per cent.	0·880	92·5	7·5	..	18,100	Critchley.
" " "	..	.	..	.	18,200	Ormandy.
" " "	0·88–885	92	8	..	18,050	Gray and Mellanby.
" 50 per cent. to 90 per cent.	0·875	..	..	..	..	Ormandy.
28. Naphthalene	1·15	94	6	.	18,000	Critchley.
				Oxy.		
29. Ethyl alcohol	0·795	52	13	35	12,700	"
Methyl "	..	..	..	..	9,600	Mahler.
Alcohol, 80 per cent.	0·863	..	..	..	10,000	"
Methylated spirit	0·815	..	..	..	11,000	Ormandy.

CHAPTER III.

CHEMICAL COMPOSITION OF FUEL OILS.

THE exact composition of petroleum is of such complexity that very special study alone will suffice for acquiring a thorough knowledge of its chemical possibilities. In connection with its use as liquid fuel, however, it is not necessary to go deeply into detail, nor in a treatise of this description is it necessary to give much more than general information on the subject. The oil chiefly used for fuel purposes is that known under the name of "residuals," "fuel oil," "gas oil," etc.; known in America as "residuum," "distillate," etc.; and in Russia, "astatki" or "mazout," the latter being the Tartar word for the residue left over from the crude oil after refining. In some cases the crude oil as it is obtained direct from the wells is also suitable for fuel purposes, provided it has been permitted to stand in the open air for a short period, in order to allow the lighter oils to pass away, and thus remove the dangerous ingredients.

The physical tests generally adopted for fuel oil are:—(1) Specific gravity; (2) flash point; (3) viscosity. The specific gravity is the weight of a given volume of oil compared to the weight of a given volume of water, and in this country is taken at 60° F. The specific gravity is determined in three ways: (*a*) By hydrometer; (*b*) by specific gravity balance; (*c*) by specific gravity bottle. The flash point is the temperature at which an oil on being slowly heated begins to evolve a vapour in such quantity as, on the application of a flame, a momentary flash, due to the ignition of the vapour, occurs; and again, the temperature at which, on being further heated, the oil takes fire on the approach of a flame and continues burning, is termed the fire point. When determining closed flash points the sample is covered, and when determining fire points and the open the sample is uncovered during the experiment. The viscosity of fuel oil is the determination of the fluidity of the oil at certain tempera-

tures, and is recorded in this country at 100° F. It is measured in various ways, but commonly by noting the time required for a definite quantity of oil to pass through an orifice of definite size or short pipe under known conditions of temperature. This principle is used in the best known types of viscometers as developed by Saybolt, Redwood, and Engler; the Saybolt viscometer being used in America, the Redwood viscometer in England, and the Engler instrument used on the Continent. The time of outflow from the viscometer is taken in seconds by a stop-watch, and the viscosity is reported in terms of the number of seconds required for 50 cubic centimetres of the oil being tested.

The chemical tests usually adopted for fuel oil are:—(1) Calorific value, (2) percentage of sulphur. The calorific value is taken in the ordinary "bomb" calorimeter. The sulphur percentage is also taken by means of the "bomb" calorimeter by estimating the amount of sulphuric acid in the "bomb." The physical and chemical tests of Mexican fuel are as follows:—Specific gravity, about ·95 at 60° F.; flash point (open), over 150° F.; viscosity, about 1500 seconds (Redwood) at 100° F.; calorific value, about 18,750 B.Th.U.'s; sulphur percentage, approximately 3·5 per cent.

Borneo and Texas crude oils are in their natural state suitable for fuel—the latter, according to some authorities, not until after the removal of some of the sulphur contents. The crude products of Russia and California have to undergo a certain course of distillation, from which a residue is obtained forming one of the best oils for fuel purposes extant The composition of some of the more important fuel oils of the world is as under; their calorific values are also appended:—

Description.	Carbon.	Hydrogen.	Sulphur.	Incombustibles.	Calorific Value. B.T.U.	Description.	Carbon.	Hydrogen.	Sulphur.	Incombustibles.	Calorific Value. B.T.U.
Borneo .	87·8	10·78	..	1·42	18,830	Roumania	87·11	11·87	·15	1·87	19,300
,, .	86·7	10·68	·03	1·6	18,800	Russia .	84·94	13·96	..	1·1	18,600
Burmah	86·4	12·1	..	1·5	18,860	Texas .	85·66	11	1·35	2	18,200
California .	84·4	11·1	·59	3·9	18,800	,, .	86·3	12·2	1·33	0·17	18,400

The oil obtained from Baku, when subjected to distillation, evolves, first, light naphtha, then kerosene to the extent of about 30 to 35 per cent.; after which a residue of "mazout" or "astatki" is left in the still, which is chiefly used as fuel. These residuals do not give off any vapour below 248° F., neither will they flash under 302° F. Moreover, they may be exposed without danger to flame; their storage and handling, therefore, present little risk. The chief components of Russian residuals are from 11 to 13 per cent. of hydrogen, from 84 to 87 per cent. of carbon, and from 1 to 1·75 per cent. of oxygen.

In reference to Texas oils, data presented to the Society of Chemical Industry (New York Section) show the composition of the Beaumont oil compared with other American oils, and also the results of distillation tests, as follows:—

ULTIMATE COMPOSITION.

	Beaumont.	Penna.[1]	Ohio.[2]
C	85·03	86·10	85·00
H	12·30	13·90	13·80
S	1·75	0·06	0·60
O and N	0·92	...	0·60
Loss on treatment with excess of H_2SO_4 .	39·0	21·0	30·00

DISTILLATION TESTS (*Engler's Flasks*).

	Beaumont. Test No. 44,651.	Ohio. Test No. 19,708.	Pennsylvania. Test No. 46,483.
Distillation begins	110° C.	85° C.	80° C.
Below 150° C. . . . per cent.	2·5	23·0	21·0
150°–300° C. . . ,,	40·0	21·0	41·0
300°–350° C. . . ,,	20·0	21·0	14·0
350°–400° C. . . ,,	25·0	27·0	2·03, 99·0
Loss on acid treatment (150°–300° C. fraction)	10·0	5·0	1·8
150°–260° C. . . . per cent.	30·0	...	...
Loss on acid treatment . ,,	8·0	...	...
Percentage of acid used . ,,	7·0	2·5	2·0

[1] Engler. [2] Mabery.

Report on sample submitted for analysis from the Kern River district:—

"This oil is practically free from low boiling naphtha, as on distillation only a small percentage passed over below 150° C., and less than 10 per cent. below 225° C. A boiling point above 360° C. was reached before the second 10 per cent. was collected.

"It shows on ultimate analysis the following composition:—

	Per Cent.
Carbon	84·43
Hydrogen	10·99
Nitrogen	·65
Sulphur	·59
Oxygen	3·34

"This gives a calorific value, by Dulong's formula, of 18,806 B.T.U. The specific gravity at 60° F. is 0·962. Flash point, 228° F. Fire point, 258° F. Vaporisation point, 178° F. Loss for six hours at 212° F., 12·01 per cent."

The percentage of sulphur varies considerably, being as high as 3·5 in some of the Mexican oils and as low as 0·06 in Pennsylvania oil.

Borneo oils are generally low in sulphur contents and of an ideal consistency for fuel purposes, and will no doubt continue to have a very important influence on the liquid-fuel question, especially in the Far East. In the Balek Pappan field, a light crude oil of about 0·870 and a heavy one of about 0·970 are obtained. A sample of the light crude oil analysed by M. Ragosine, gave the following results:—

Specific gravity at 15° C. . . . . . . 0·896

FRACTIONAL DISTILLATION.

No. of Fraction.	Boiling Point. ° C.	Per Cent.	Specific Gravity.	Quantity of Products.
Kerosene 1st	130–150	0·9	...	...
2nd	150–170	3·0	0·783	1. Loss . . . 1·5 p.c.
3rd	170–190	10·5	0·794	2. Kerosene distillate . . 44·0 ,,
4th	190–210	6·0	0·811	3. Solar distillate . 8·0 ,,
5th	210–230	6·4	0·831	4. Residuals . . 46·0 ,,
6th	230–250	9·0	0·850	
7th	250–270	9·0	0·874	100·0 p.c.
8th	270–290	8·5	0·892	
Residuals	...	46·7	0·975	

In the Sanga field, there are also a heavy and a light crude oil.

The heavy crude oil has a specific gravity of 0·980, and contains only a certain quantity of solar oil (about 15 per cent.) and 85 per cent. of residuals. The light crude oil showed the following composition:—

Specific gravity of the crude oil at 15° C. . . 0·862

FRACTIONAL DISTILLATION.

No. of Fraction.	Boiling Point. °C.	Per Cent.	Specific Gravity.	Quantity of Products.
Benzine . .	110–130	11·2	0·768	1. Benzine and loss 18·5 p.c.
Kerosene 1st .	130–150	11·3	0·783	2. Kerosene distillate . . 51·9 ,,
2nd .	150–170	10·5	0·799	3. Residuals . . 29·6 ,,
3rd .	170–190	7·3	0·811	
4th .	190–210	8·0	0·828	
5th .	210–230	6·5	0·850	
6th .	230–250	7·5	0·876	
7th .	250–270	7·7	0·905	
8th .	270–290	3·6	...	
Residuals .	...	26·0	0·971	

The residuals in both cases are liquid.

If the two descriptions of oils from Balek Pappan and Sanga-Sanga are treated together in equal proportions, then the relative quantity of products obtained at the refinery are:—Benzine and loss, 9 per cent.; kerosene, 26 per cent.; solar oil, 7 per cent.; residuals, 58 per cent. Samples of this taken at Singapore gave the following tests:—

	No. 1.	No. 2.	No. 3.	No. 4.
Specific gravity at 15° C. .	0·962	0·968	0·965	0·961
Flash point (by Martins Pensky apparatus)	107° C.	104° C.	68° C.	84° C.
Viscosity (by Engler-Ragosine)	2·9	3·2	2·3	2·3
Water	present	present	present	absent

The very great difference in flash point was due to the

fact that the refinery produces two classes of liquid fuel: the first, with a flash point above 100° C., to supply places where the high flash point is required by the laws of the country (for instance, in British India and Japan); and the second, with a lower flash point, being adapted to countries where there are as yet no flash point regulations.

In another analysis of Texas oil made by Prof. Thiele, results were obtained as shown below:—

Analysis of Crude Oil, Strata 272 Feet below Surface.

Fraction.	Temp. °C.	P.c. by Vol.	Sp. Gr.	Colour.
1.	...	trace	...	White.
2.	212–266	0·07	...	Yellow.
3.	266–320	0·03	...	Yellow.
4.	320–392	1·59	0·684	Yellow.
5.	392–572	19·49	0·840	Bl. Fluor.
6.	...	...	...	Bl. Fluor.
7.	572–641	5·15	0·782	Dark Yellow.
Residue . .	...	71·11	0·978	Black.
	Total .	97·44		

An analysis from samples from two cargoes of Mexican crude fuel oil, which, as stated elsewhere, promises to become one of the most promising supplies for the United Kingdom, shows, as will be seen from the table below, a considerable percentage of sulphur and solid residuum:—

	No. 1.	No. 2.
Specific gravity at 60° F.	0·944	0·942
Beaumé ,, ,,	18·4°	18·8°
Flash point (closed) .	78° F.	102° F.
,, ,, (open) .	104° F.	120° F.
Fire test	165° F.	180° F.
Viscosity at 100° F. .	1080 seconds (Redwood)	920 seconds (Redwood)
Sulphur	3·44 per cent.	3·35 per cent.
Calorific value . .	19,700 B.T.U.	19,000 B.T.U.
Colour	Black	Black
Water	Nil	0·5 per cent.
Asphalt	. . . . . .	3·7 ,,
Carbon (coke) . .	. . . . . .	1·2 ,,

ANALYSES OF VARIOUS CRUDE OILS.

Source of Supply.	Sp. Gr.	C.	H.	N.	O.	S.	Analyst.
Ohio . . .	827	85·4	14·6	...	...	...	Engler.
Ohio . . .	...	86·3	13	...	...	...	Redwood.
California . .	984	86·3	11·7	1·25	...	·84	Mabery.
California . .	846	86·2	13·08	...	...	...	,,
California . .	...	86·9	11·8	1	...	...	Redwood.
Virginia . .	...	85	13·3	...	...	...	,,
Texas . . .	912	85	12·3	0·9	...	1·75	Richardson.
Canada . .	...	83·9	13·3	...	...	0·9	Mabery.
Burmah . .	855	83·8	12·7	...	3·5	...	Redwood.
Russia (Baku) .	884	86	13·6	...	...	...	,,
Peru . . .	850	86	13	0·07	0·07	0·04	,,
Mexico . .	940	82	11	1·7	...	3·3	,,

According to Dr A. Sommer, M.S.N.E., oils having an asphaltum base contain more sulphur, have a higher density, and a greater tendency to polymerise and solidify than oils with a paraffin base, which harden up in contact with air, and are more solvent; asphaltic oils also decompose at lower temperatures than those with a paraffin base.

ANALYSES OF AMERICAN CRUDE OILS BY DR SOMMER.

State.	Specific Gravity.	Boiling Temp. °C.	Paraffin. Per Cent.	Asphalt. Per Cent.	Sulphur. Per Cent.	Colour.	Percentage of Distillation at °C.				
							100.	150.	200.	250.	300.
Pennsylvania	792	23	2·8	...	0·15	Greenish brown.	6	23	?	?	60
Colorado .	830	96	2·5	0·04	0·3	Dark brown.	1	6	21	35	48
Louisiana .	890	152	0·35	0·1	0 33	Dark brown.	?	?	8	17	41
California .	940	139	1·48	14·9	3·3	Black and viscous.	0	1	4	13	23

Further, those crude oils which are characterised as having a paraffin base have a comparatively lower density, and contain less sulphur than asphaltic oils.

Paraffin oils also have a low solvent power, a high degree of capillarity, are less affected by exposure to air, and do not polymerise at ordinary temperatures.

As will be gathered from the foregoing, mineral or petroleum oils are composed of hydrogen and carbon in different proportions according to the nature of the crude oil.[1] The Pennsylvania oils belong to the *paraffin* series (chemical formula C_nH_{2n+2}) and yield a larger percentage of gasolene and light products than do the California, Texas, and Mexico oils, which belong to the *olefin* series (chemical formula C_nH_{2n}). By referring to the chemical formula, it will be seen that the Pennsylvania oils contain more hydrogen in proportion to their carbon constituents, and this accounts for their light gravity and larger yield of gasolene.

In addition to the oils mentioned above, there are the oils obtained from the Illinois and Oklahoma fields. These, oils seem to be a combination of both the *paraffin* and *olefin* series, as both paraffin wax and asphaltum are obtained from these crudes. The gravities of these latter oils range between those of the Pennsylvania and the California and Texas oils. Their yield of gasolene is greater than that of the asphalt base oils and less than that of the paraffin base oils.

According to Percy J. Friday,[2] liquid hydrocarbons derive their name from the two elements—carbon, a solid of which charcoal and coke are particular forms, and hydrogen, a gas which plays a very important part in all acids and in water. Nearly all of these compounds are liquid; those, however, which contain a very large percentage of hydrogen are gas. As the hydrogen percentage decreases, the hydrocarbons become heavier until finally they become solids.

The hydrocarbons are again divided into a number of different series, the most important of which is the paraffin, and makes up over 95 per cent. of Pennsylvania crude petroleum. The members of this series have regular formulæ, and in every molecule of any one of the compounds of this series, for any number of carbon atoms,

[1] H. L. Burleson.

[2] *Ignition, Carburetion, Lubrication.*

there are twice as many hydrogen atoms plus two—*e.g.* methane (the first member of the series) has the formula CH_4, and means that in each molecule of methane there is one atom of carbon, and four $(2 \times 1 + 2)$ atoms of hydrogen. What is known as the graphic formula of this compound is

$$\begin{array}{ccccc} & & H & & \\ & & | & & \\ H & - & C & - & H \\ & & | & & \\ & & H & & \end{array}$$

The second of the series is ethane and has the formula C_2H_6. The graphic representation of this formula is

$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & H \\ & & | & & | & & \\ & & H & & H & & \end{array}$$

To illustrate this regularity of the paraffin compounds, the graphic formula of hexane (the principal constituent of gasolene) is also adduced. The name hexane signifies six carbon atoms, and its formula is C_6H_{14}, or graphically represented is

$$\begin{array}{ccccccccccccccc} & & H & & H & & H & & H & & H & & H & & \\ & & | & & | & & | & & | & & | & & | & & \\ H & - & C & - & C & - & C & - & C & - & C & - & C & - & H \\ & & | & & | & & | & & | & & | & & | & & \\ & & H & & H & & H & & H & & H & & H & & \end{array}$$

The regularity of formation of the series is remarkable; also it will be noticed that every C, representing a carbon atom, has connected to it four lines. Every H, representing a hydrogen atom, has one. These are called valencies in chemistry. Carbon is said to have a valency of four and hydrogen a valency of one.

Table I. gives the names, formulæ, boiling point, specific gravity as compared to water, and gravity according to the Beaumè scale, for the first sixteen members of the paraffin series of hydrocarbons. This list could be carried much further, as all of these and many others (extending up to C_{35}, H_{72}, or higher) are found in crude petroleum.

TABLE I.—THE FIRST SIXTEEN PARAFFIN HYDROCARBONS FOUND IN PETROLEUM.

Name.	Formula.	Boiling Point. °F.	Per Cent. C.	Per Cent. H.	Sp. Gr.	Deg. Beaumè.
Methane (Fire damp)	CH_4	A gas.	75·00	25·00	·559	...
Ethane	C_2H_6	A gas.	80·00	20·00	...	...
Propane	C_3H_8	A gas.	81·81	18·19	...	...
Butane	C_4H_{10}	34° F.	82·80	17·20	·6	...
Pentane	C_5H_{12}	86	83·33	16·67	·628	...
Hexane	C_6H_{14}	156	83·72	16·28	·664	·81
Heptane	C_7H_{16}	208	84·00	16·00	·669	·79
Octane	C_8H_{18}	259	84·21	15·79	·703	·69
Nonane	C_9H_{20}	277	84·38	15·62	·741	·59
Decane	$C_{10}H_{22}$	316	84·51	15·49	·757	·55
Endecane	$C_{11}H_{24}$	360	84·61	15·39	·765	·53
Dodecane	$C_{12}H_{26}$	386	84·70	15·30	·776	·50
Tridecane	$C_{13}H_{28}$	420	84·78	15·22	·792	·46
Tetradecane	$C_{14}H_{30}$	462	84·85	15·15	...	...
Pentadecane	$C_{15}H_{32}$	497	84·90	15·10	...	...
Hexadecane	$C_{16}H_{34}$	536	84·94	15·06	...	...

TABLE II.

Products.	Boiling Point. °F.	Sp. Gr.	Deg. Beaumè.
Rhigoline	113	·59–·60	111–107
Chimogene	122–138	·64–·66	91–85
Gasolene	158	·66–·67	85–81
Naphtha C	176–216	·68–·70	78–72
Naphtha B	200–220	·71–·72	69–66
Naphtha A	230–250	·72–·74	66–59
Kerosene	300–480	·75–·86	58–38

Methane, the first member of the series, is a gas at ordinary temperatures. It can be liquefied only by great pressure and low temperature. It is found in a free state in large quantities. Often large cavities in coal beds are filled with this gas under pressure. The name "fire damp" is given to it by miners because of the serious explosions caused by its ignition. (Fire damp usually contains about 96 per cent. methane, 0·5 per cent. carbon-dioxide, and 3·5 per cent. nitrogen.) Methane is often known as "marsh

gas," as it is also formed by the decay of vegetable and animal matter in marshes and stagnant pools.

Methane forms a large per cent. of the natural gas of oil-wells. Those containing the largest per cent. are the Olean N.Y. gases, which are about 96½ per cent. CH_4. Other natural gases decrease in methane from that down to about 67 per cent. Those which are highest in methane are also highest in calorific value, as the calorific value of methane itself is very high, it being about 23,600 heat units per pound. Coke oven gas contains about 35 per cent. methane, producer gas 2 to 8 per cent., and water gas less than 1 per cent. These gases, however, are very rich in other constituents of high calorific value.

Methane is the only member of the series that is found in appreciable quantities in a free state. The other members are found in mixtures to form the different products given in Table II. Although methane and propane are gases when separated, they are found in solution in some of the lighter products in the table. The boiling point and specific gravity of products in this list are not accurate but are only approximate, as the points of distillation of different products change as the demand for them changes. For example, nearly all of the naphtha given in this table is now sold as gasolene, while years ago it formed a part of kerosene. The change is due to an increased demand for gasolene without a proportionate increase in the demand for kerosene. Nearly everyone can call to mind the fact that at one time kerosene was somewhat dangerous. This was due to the presence of some of the hydrocarbons now contained in gasolene. This does not render gasolene more dangerous, but makes it less dangerous. But this is because different precautions are taken with gasolene than with kerosene (*vide* figs. 110–111, Chapter XI.).

Rhigolene and chimogene are of very little commercial value because of their scarcity. Rhigolene is used to some extent as an anæsthetic and in the arts, and is known as petroleum ether.

Gasolene proper, otherwise known as benzine, motor-spirit, petrol, essence, etc., is chemically composed of pentane, hexane, and heptane, differing in proportion as the grade of gasolene differs. Commercial gasolene is

now found to differ very much from that shown in the table. One chemical authority has said, "The name 'gasolene' is now used simply to cover up a multitude of sins." Gasolene with a specific gravity of ·636 to ·657 (90° to 80° Beaumè), as given in the table, is used for the extraction of oils and in carburetted air lighting systems.

High-grade motor gasolene has an average specific gravity of about ·686 (74° Beaumè), and is composed largely of naphtha C as given in Table II.

Common motor-spirit a few years ago had a specific gravity of about ·69 or ·70 (about 71° Beaumè). This was composed principally of naphtha B and C. There are now grades much lower than this and containing naphtha A in considerable proportion.

Gasolene of ·683 sp. gr. (75° Beaumè) when analysed proves to be about 80 per cent. hexane, 18 per cent. heptane, and 2 per cent. pentane. This gives a chemical composition of 83·8 per cent. carbon and 16·2 per cent. hydrogen. The composition is expressed by $41{\cdot}86C_6H_{14} + 6{\cdot}48C_7H_{16} + C_5H_{12}$.

Gasolene has a calorific value of 18,000 to 20,000 B.T.U. per pound.

For the complete combustion of one pound of gasolene about 190 cubic feet of air is required. As one pound of fuel forms 26 cubic feet of vapour, a perfect combustible mixture is made up of one part vapour and seven and three-tenth parts air by volume.

An excess of fuel will cause incomplete combustion. An increase of air up to about 10 to 1 may cause an increased efficiency, even though all the air does not enter into the reactions of combustion.

Kerosene of 150° fire test is made up principally of decane, but also contains a large percentage of nonane and hexadecane. The vapour which forms above it when warm is principally nonane.

The heat value of kerosene is about 21,000 to 22,000 B.T.U. per pound, and is therefore higher than gasolene.

For the complete combustion of kerosene vapour 200 to 210 cubic feet of air is required per pound.

With the increasing demand for motor-spirit for use in

automobiles and the like, the specific gravity of this fuel has a much wider range than it had ten years ago,[1] brands of motor-spirit under different names, and made up of various grades of petrol, paraffin, and benzole, being now in common use. But as a matter of fact, the specific gravity is not so important as the boiling point of the fuel. The temperatures at which the various constituents of motor-spirit evaporate should lie as closely together as possible, so as to produce a uniform result.

As a substitute for petroleum spirit, benzole is one of the fuels that have met with the greatest measure of success. Benzole is manufactured by the fractional distillation of coal-tar. Pure benzole is of uniform composition, and in this respect is unlike any of the distillates from petroleum; it conforms to the formula C_6H_6, and boils at 175° F.

But as coal-tar under conditions (*vide* p. 17, Chapter I.) only yields so small an amount of benzole, this fuel is not often used in the pure state, but mixed with xylol, $C_6H_6CH_3CH_3$, toluol $C_6H_5CH_3$, and cumol C_6H_5CH, CH_3CH; which compounds, as their formulæ show, are richer in hydrogen than pure benzole, and therefore lighter and of greater thermal value; however, their average boiling point is 50 to 70° F. higher than pure benzole, but provided their admixture does not exceed the proportion of one of toluol, etc., to ten or twelve of benzole, the resultant fuel, known as commercial benzole, if washed fairly free from sulphur and a gummy substance called coumarine, forms a very successful substitute fuel for petroleum spirit, and one that can be produced in considerable quantities from bituminous coal, lignite, peat, etc. Pure benzole, C_6H_6, solidifies at 40° F.,[2] and therefore requires to be mixed with a percentage of more volatile fuel, such as toluol, C_7H_8, and xylol, C_8H_{10}. Benzole such as known as 90 per cent. is the brand most generally used for motor work, and has a sp. gr. of ·885; this is of a volatility that 90 per cent. of it will boil away at 100° C.; that known as 50–90 benzole is a mixture with a greater percentage of toluol chiefly, of which 50 per cent. will boil away at 100° C. and 90 per cent. at 120° C. The calorific values of

[1] E. A. Langdon. [2] W. R. Ormandy.

benzole, toluol, and xylol are approximately equal although their boiling points and sp. gr. differ, the B.T.U. varying from 18,100 to 18,460 respectively.

Another proposed substitute for petroleum spirit is denatured alcohol, known as methylated spirit, which consists of 82 per cent. ethyl alcohol, plus 10 per cent. wood spirit, plus 8 per cent. of water.

Pure ethyl alcohol, as its formula C_2H_5OH shows, contains a large percentage of hydrogen, but the oxygen content not only reduces its thermal value considerably but enables it to combine readily with water, a 10 to 15 per cent. dilution rendering it unsuitable as a substitute fuel for motor work. In its pure state ethyl alcohol has a thermal value equalling 12,700 B.T.U. per pound, methyl alcohol 9600, and methylated spirit of ·815 sp. gr. a value equalling 11,600 B.T.U. per pound.

Naphthalene, which is solid at normal temperatures, can also be used as a substitute for petroleum spirit for power purposes when melted, but need not be considered seriously as the supply is comparatively limited. Naphthalene has a sp. gr. of 1·15, melts at 174° F., boils at 424° F., and consists principally of carbon, as its formula $C_{94}H_6$ denotes.

In concluding this chapter on the chemical composition of the various liquid fuels, it may be interesting to add a table for comparison, showing the composition, calorific value, and evaporative power of different kinds of coal.

Coal (from several Samples).	Specific Gravity.	C.	H.	O.	S.	Ash.	Moisture.	B.T.U.	Lbs. of Water evap.
Welsh . .	1·315	83·8	4·8	1·0	1·4	4·1	4·9	14,470	14·98
Newcastle . .	1·256	82·1	5·3	1·3	1·2	5·7	3·8	14,432	14·94
Derby and Yorks	1·292	79·7	4·9	1·4	1·0	10·3	2·6	13,582	14·06
Lancashire .	1·273	77·9	5·3	1·3	1·4	9·5	4·6	13,552	14·03
Scotch . .	1·260	78·5	5·6	1·0	1·1	9·7	4·0	13,804	14·29
Average British .	1·279	80·4	5·2	1·2	1·25	7·87	4·0	13,968	14·46

CHAPTER IV.

CONDITIONS OF COMBUSTION IN OIL-FUEL FURNACES.

THE opportunities of observing the process of combustion, as well as other phenomena, characteristic of the burning of oil as fuel are of considerable moment, and in this connection some observations have been made by Prof. Vivian B. Lewes, who has dealt with the subject from a purely chemical point of view, as follows:—

"When coal is burnt in a furnace," says Prof. Lewes, "a large proportion of the heat transmitted to the water takes place by radiation, and it is clear that in our method of burning oil it will have to be determined whether it is better to so arrange the air supply as to produce almost non-luminous flames, such as those given by the atmospheric burner, or whether the air supply should at first be limited, so as to give a highly luminous flame, and the air needed to complete the combustion only added when the combustion chamber is reached. '*A non-luminous flame gives but little radiant heat, whilst the incandescent particles in a luminous flame give a very considerable amount.*' My own impression is that to facilitate the transmission of a portion of the heat as radiant heat the flame in the furnace itself should be luminous, and that the combustion should be completed by the addition of more air at the entrance to the combustion chamber before the tubes are reached.

"The transmission of heat from a non-luminous flame in the furnace to the water in the boiler is but small, as the contact of the surface of the furnace crown extinguishes the flame, and leaves a layer of badly conducting gases

between the metal and the flame. It is for this reason that, when the mass of radiating fuel on the furnace grate is done away with, and is replaced by the flame of burning hydrocarbons, it becomes necessary to use fire-brick or other refractory material in the furnace, in order that it may become highly heated, and by its radiation aid the transmission of heat to the water in the boiler.

"There is another side, however, to the question which must not be overlooked, and that is, that it is necessary to dilute the oil gas as far as possible before combustion, in order to prevent the deposition of carbon, which, once formed, is very difficult to reburn, and is one of the chief causes of smoking. If the effect of the steam is merely the mechanical one of injecting, and afterwards diluting, the oil gas, and no chemical action took place, the advantage would be entirely on the side of such injectors as do their work by pressure and not by steam, but it must be remembered that, as the oil spray is heated in the furnace space in presence of the steam, chemical action takes place and greatly simplifies the composition of the hydrocarbons.

"It may be roughly taken that the petroleum residue chiefly employed will approximate to $C_{12}H_{26}$, that is to say, will be a mixture of hydrocarbons, the composition of which is around this point, and if this be brought in contact with sufficient steam in the hot furnace space, the action, if complete, would result in the formation of carbon monoxide and hydrogen—

$$C_{12}H_{26} + 12H_2O = 12CO + 25H_2;$$

whilst under ordinary working conditions, the proportion of steam being far less than this, the result would be hydrocarbons of a more simple molecular structure diluted by hydrogen and carbon monoxide, such a mixture being comparatively easy to burn without formation of smoke, whilst the rich oil gas and oil tar vapours, formed by the heating when no steam is there to aid the chemical interactions, are excessively difficult to burn without the formation of smoke."

"Some observers have tried to argue that the utilisation of steam for direct pulverisation of the oil adds enormously

to the heating effect by producing in this way hydrogen and carbon monoxide, but this, of course, is an utter mistake, '*as it takes just as much heat to break up the steam as is evolved by the after combustion of the products formed;*' that is to say, the balance of heat will remain unchanged, whether the oil be burnt alone with air, or whether it be decomposed by steam and the products then burnt, the great advantage of the steam being to facilitate the combustion of the oil without the formation of smoke, which undoubtedly must give increased heat by preventing the escape of unconsumed products.

"One of the questions which is of the greatest possible importance in the combustion of liquid fuel is the regulation of the air supply in such a way as to complete the combustion within the area possible to allow in the boiler. This requires most careful experimental research in order to determine not only the volume, but also the particular stage in the combustion at which it answers best to add it.

"In the combustion of liquid fuel the oil is practically entirely converted into gas, vapour, and floating particles of finely divided carbon before combustion begins, or at any rate before any large amount has been consumed. This requires a large combustion area, as the volume of air needed to complete the action and prevent smoking is very great, whilst with coal the combustion of the largest proportion of the fuel takes place on the furnace grate, and it is only the escaping gases distilled out of the coal and formed by the incomplete combustion that have to be burnt in the crown of the furnace and combustion chamber.

"The question of combustion area and air supply needed for the use of liquid fuel is made clear when one considers, in figures, the work which has to be done. With a service vessel under full steam, if the best Welsh coal is used, there will be little or no smoke, showing that combustion has been fairly complete, whilst one knows that if one took a Newcastle or Durham coal there would be abundant black smoke from the funnel, showing that already the combustion area and air supply were insufficient to deal with the work that had to be performed. If one took the actions taking place with a bituminous coal as representing the maximum efficiency of combustion that could be obtained

by that particular arrangement of boiler and furnace, one would be certainly overstating and not understating the efficiency.

"The action of the heat from the fire in the grate when the coal is first charged in very closely resembles the actions that take place in the gas-maker's retort, as the red-hot fuel below is raising the fresh fuel above to a temperature of about 1000° C., and is preventing any large amount of air from getting through the bed of incandescent carbonaceous material to it. Under these conditions a ton of bituminous coal would yield 10,000 cubic feet of gas and 10 gallons of tar in the condition of vapour, whilst 75 per cent. of the weight of the coal would be left to burn on the fire grate, a certain proportion of which, by incomplete combustion, would yield carbon monoxide to add to the body of gas to be burnt up in the crown of the furnace and the combustion chamber.

"On the other hand, when a ton of astatki is converted into gas, on being injected into the furnace, it yields double this quantity, *i.e.* 20,000 cubic feet of gas and about 12 per cent. only of residual tar in the form of vapour and carbon particles. Not only is the volume of gas thus yielded twice as great in the case of oil fuel as in the case of coal fuel, but it is a gas which, being far richer in hydrocarbons, requires a far greater volume of air for its complete combustion than was the case with the gas developed from the coal, so that it can easily be understood that a furnace with its combustion area and air draught arranged for coal, cannot be expected to deal with nearly the same weight of liquid fuel.

"It must be borne in mind that the area over which the combustion spreads is governed by the length of travel of the combustible gases before they find the necessary amount of atmospheric oxygen for their complete combustion, and that the conditions of air supply mean, to a great extent, regulation of combustion space; but whilst doing this and completing the combustion of large volumes of oil in a small space, a limiting factor will soon be found in the intensity of the temperature attained, so that the important factor to be determined is the weight of oil that can be consumed per cubic foot of combustion space, without

throwing an undue strain from overheating on the material of boiler and fittings."

The experiments carried out by Mr E. L. Ordo were made with crude Borneo oil, the composition of which is: carbon, 87·9 per cent.; hydrogen, 10·78 per cent.; and oxygen, 1·24 per cent. The flash point is 211° F., and the boiling point 395° F. The calorific value, determined by the Bomb calorimeter, is 18,831 B.T.U.

All fuel oils are exceedingly complex, being made up of a number of combinations of carbon and hydrogen which only a chemist who has devoted himself to investigating hydrocarbons can appreciate at their true significance. The importance of this point for the practical purposes of the engineer lies in the fact that the various constituents of the fuel give off vapour at temperatures varying from about 100° F. up to the boiling point of the oil, and when the boiling point is approached—unless special precautions are taken—a residue of solid carbon is formed which will soon choke any pipes or narrow passages through which the fuel may have to pass.

An important characteristic of these hydrocarbon compounds is that in the presence of superheated steam they can be completely distilled without cracking, and the explanation of this fact has been stated to be that in the presence of superheated steam the boiling point, or, more correctly, the mean boiling point, of the oil is lowered. This distillation, however, does not apparently take place with any other medium but steam.

To ensure distillation it is necessary that the temperature of the oil should be raised to as near the boiling point as possible before it is admitted into the presence of the steam, and it is in this part of the process that the danger of cracking appears. In the apparatus under observation this difficulty had been overcome, and, so far as it has been possible to ascertain by ordinary means, complete vaporisation was secured. The vapour thus produced can be completely oxidised by the amount of air chemically necessary, and a larger quantity of oil can, therefore, be treated in the same furnace space than by either of the two other systems, while the combustion, as shown by the analyses of waste gases, is complete.

	I. Per Cent.	II. Per Cent.
Carbon dioxide	13·2	12·6
Oxygen	3·6	4·0
Carbon monoxide	...	...
Hydrocarbon gases	...	...
Hydrogen	...	...
Nitrogen	83·2	83·4

The only feature calling for remark is the somewhat large percentage of uncombined oxygen, which is no doubt due to leakage around the smoke-box. As regards efficiency, an evaporation of from 15 to 16 lbs. from and at 212° should always be obtained with dry Borneo oil.

The hydrocarbon vapour is exceeding unstable, and appears to depend for its existence entirely on temperature. The exact form in which the combustion of these hydrocarbon vapours takes place does not seem to be clearly understood. The appearance of the flame at a distance of a few inches from the nozzle of the burner suggests that at that point the hydrocarbons are burning in the form of acetylene, which all gaseous hydrocarbons do at a temperature of 1000° F. As the flame proceeds further into the furnace, however, and the temperature becomes higher, the hydrocarbon combination must break up, and the rest of the vapour is probably burned as carbon monoxide and hydrogen.

It has been suggested by some of the early writers on the subject that liquid fuel has a higher calorific value than solid fuel of the same chemical composition, from the fact that a certain amount of heat has been rendered latent in passing it from the solid to the liquid form; and it has therefore been argued that heat values calculated on the basis of solid carbon are underestimated to the extent of this latent heat of liquefaction. Dr Paul, who investigated the subject very closely, has suggested 6000 B.T.U. as the value of the heat thus lost, but as this is the value assigned by Rankine to the latent heat of the gasification of solid carbon, it would appear to be too high for the latent heat of its liquefaction. The determination of the heat value of petroleum by the Bomb calorimeter does not show the existence of this latent heat, and Dr Paul comes to the conclusion that it is not probable that petroleum, when used as fuel, can be made to evaporate more than about

16 lbs. of water from and at 212° F. This agrees with nearly all the well-authenticated results that are on record.

Taking Borneo oil as an example, a heat balance sheet that has been experimentally obtained is given below.

HEAT BALANCE SHEET OF BORNEO OIL.

Loss due to Moisture.	Units of Evaporation.			
1. $\frac{10.78}{100} \times 9 \times (212 - t) + 966 + 0.48(T - 212)$ (where t = *initial temperature of oil.* T = *temperature of escaping gases.*)	1·15	1·0	1·2	1·19
2. Losses due to heat carried off in escaping gases. $\frac{1 + A^1 \times T}{4000}$. ($A$ = *weight of air required for combustion (observed)*)	1·46	1·6	2·3	2·21
3. Loss due to radiation (observed) . .	1·3	1·4	1·3	1·38
4. Heat employed in evaporation . .	15·4	15·4	14·5	14·6
Total heat value of oil . .	19·4	19·4	19·4	19·4

The heat lost in radiation was measured at a separate trial, the amounts thus found were interpolated in the balance sheet, and observed to agree very closely with the result found by difference in the usual way, but the second, when the observed evaporation was undoubtedly too high, the observed evaporation results were 15·4, 15·95, 14·6, and 14·8 respectively. The difference between the first and second pairs of experiments is due to the presence of water in the oil. This exercises a very important function on the behaviour of the fuel, and is responsible for much of the difficulty that has attended its use. "*The actual reduction of the heat value of the fuel* =*13·14 B.T.U. per 1 per cent. water, in addition to the loss of the oil which it replaces*"; for example, 1 lb. of oil mixed with 10 per cent. water evolves

$$18{,}831 \times 0.9 = 16{,}947.9 \text{ B.T.U.}$$

less 131·4 ,,

a difference of 1915·5 B.T.U., or a loss in evaporative power of nearly 2 lbs. of water from and at 212°.

Besides this actual loss of heat, the presence of water destroys the conditions necessary for perfect combustion, and this occurs and may cause considerable damage to boilers of the ordinary marine type, although the quantity is not sufficient to extinguish the flame. The first effect is naturally to reduce the temperature of the flames and thereby increase their length, thus moving the point of highest temperature further into the furnace, which has the effect:—

1st. Of rendering a large portion of the furnace heating surface entirely useless;

2nd. Of raising the temperature in the combustion chambers to a point which may be hurtful to the material; and

3rd. Of causing the last stage of combustion to take place in the smoke-box and funnel.

The conditions that attend and the reactions that take place in burning liquid fuel in boiler furnaces present a problem which has apparently not received the attention which it deserves. Petroleum vapour depends entirely on temperature, and it is therefore almost impossible to collect samples when actually burning it in a furnace. It seems obvious that the first effect of the furnace heat on the petroleum spray is to liberate hydrocarbon vapours, and to ignite them on the outer surface of the jet. The ignition raises the temperature of the whole of the jet, and probably dissociates some at least of the hydrocarbon vapours into carbon monoxide and hydrogen. In what form the undissociated hydrocarbon vapours burn it is difficult to conjecture, but the appearance of the flames suggests that acetylene is present. This might conceivably arise from the reaction $CH_4 + CO = H_2O + C_2H_2$. As the temperature of the flame rises, the hydrocarbons are probably all dissociated, and burn as CO and H to CO_2 and H_2O without further change. When the conditions are satisfactory, the flames are opaque and dazzling white in colour for a distance of some 6 inches from the nozzle of the burner, become semi-transparent and almost violet in colour at the middle of their length, and shade into red at the end. In burning oil which is mixed with water the combustion is incomplete, the violet colour never appears, and the

end of the flame is dark red and fringed with smoke. In some cases, where water is present in comparatively small quantities, the end of the flame is white and presents the appearance of acetylene, which may arise from want of sufficient heat in the flame to decompose the hydrocarbons. This has been observed when, although no smoke was formed and the air supply was not more than 20 per cent. above what is chemically necessary for the fuel, the evaporative performance of the boiler was poor, which confirms the existence of a low furnace temperature.

Needless to add, the maintenance of a low stack temperature is an extremely important point in the economical working of an oil-fired boiler, for the heat lost per pound of fuel when even the minimum quantity of air is admitted to the furnace is never less than 7 to 8 per cent. of the total value of the fuel—*e.g.*, assuming a stack temperature of, say, 420° F. above that of the stokehold, and a fuel having a calorific value of 19,000 B.T.U., and containing 83 per cent. C + 12 per cent. H + 3 per cent. S + 2 per cent. N, moisture, and other incombustibles: The B.T.U. carried away by the products of combustion will be 1493 for each pound of fuel burnt, and be equal to 7·8 per cent. of its total heat value. The minimum amount of air thus required is 15 lbs., of which the C contents of the fuel will combine with 133 cubic feet, the H contents with 61 cubic feet, and the S contents with 2 cubic feet, taken at a temperature of 70° F.

But as in oil-firing 20 to 25 per cent. excess air must be supplied in order to obtain complete combustion, the stack loss will therefore be increased to 9·7 per cent.; and when the excess air supply is further increased to 50 per cent., as is often the case, then the heat carried away by the stack will amount to as much as 12 per cent., and demonstrates the advantage of an oil-firing system in which the air supplied to the furnace can be highly pre-heated and closely regulated to the feed requirements of the particular oil being burned.

CHAPTER V.

EARLY COMBUSTION METHODS FOR OIL FUEL.

ALTHOUGH there is no intention of making this book an historical record in any lengthy manner, it will be desirable, as well as of value, to give a general survey of the early methods and appliances which have been used, and of the experiments which have been carried out for improving the appliances for adapting oil to furnace work.

As far back as 1861 a mechanic named Werner, engaged in a refinery in Russia, first suggested that the refuse oil might be burnt as fuel. He adopted various contrivances, but ultimately settled on an apparatus consisting of a series of grates or griddles, over which the liquid trickled and burned. A patent was taken out by him for this device in 1867, and many firms used it, but gave it up when improved appliances were available.

In 1862 attention was directed in America towards the application of petroleum for heating and power. Another early method of burning the oil was by means of a pan or step over which the oil flowed and was ignited, while almost at the same time Shaw and Linton patented in America a furnace in which the fuel was conveyed into the interior in a gaseous state, the oil being previously heated and made to give off its lighter oils, which were subsequently consumed inside the furnace. Undoubtedly, this was a more advanced idea than that of burning the oil in its natural state openly in the bottom of the hearth, and reference will be made to this principle later. In the year following (1863) the first spray furnace was introduced into America by Brydges Adams for use on locomotives; yet, in spite of this great improvement and the more perfect combustion of the fuel

obtained, a year later Richardson introduced into England what was known as an oozing furnace. In this furnace, which was experimented with by the inventor in conjunction with the Admiralty, the bottom is lined with ordinary burned slack lime, spread evenly at the top, but with a number of small vaultings at the bottom of the layer. The oil enters these spaces from tanks, and penetrating the lime, which acts as a sort of wick, becomes ignited and is consumed. Later experiments were made with this method of burning

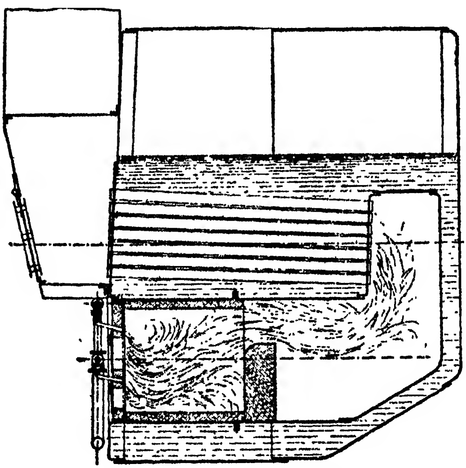


FIG. 1.—Audouin's furnace.

the oil, with the result that a commission appointed by the Admiralty reported very favourably thereon, though the system was not adopted, owing to the prohibitive price of liquid fuel. The experiments, however, served to show that unmixed oils had a greater evaporative power than mixed, the latter in this case consisting of tar oil and shale oil, and, in one instance, tar, shale, and American crude oils. The next year (1864), another drop furnace (fig. 1) was invented by Audouin in France. But in the year following a great step forward was taken by Aydon, Wise, and Field (London), by introducing their nozzle-sprinkler, which marked an era in the use of liquid fuel.

In this connection it would appear that the honour of inventing the first apparatus for injecting oil into the furnace in the form of a spray rests between Aydon and a Russian named Spakovsky. The latter used a blast of hot air, for which he obtained an English patent in June 1865; whereas Aydon employed superheated steam, for which he also obtained an English patent within three months of Spakovsky's specification. In view of the important developments that have taken place with both these systems,

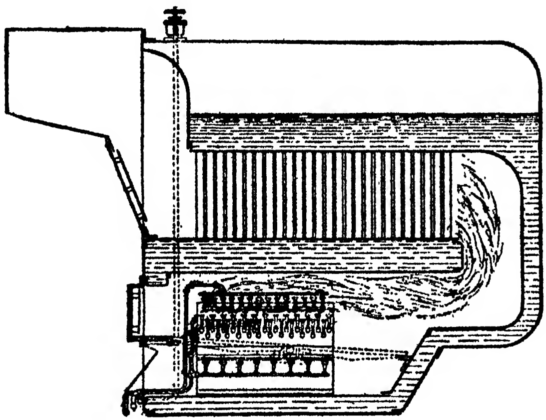


FIG. 2.—Foote's gas furnace.

the credit of originating practical methods of burning residual oils is thus attributable to both these inventors.

In 1867 came another gas furnace (fig. 2), invented by Foote in America, which was experimented with by the U.S. Navy Department on board a gunboat; but although the results of the tests were said to be excellent, little more was heard of the method, which, from a description, appears to have been somewhat complicated. Another of these gas furnaces was introduced into England in 1868, and was tried on a steamship, the *Retriever*, of 500 tons. The working of this system seems to have given satisfactory results, and a short description of it will be presented.

In this same year St Claire-Deville introduced a new

drop furnace in France, something on the same principle as that of Audouin, which was used under the boilers of the steam yacht *Puebla*. In this instance a heavy tar oil of a specific gravity of 1·044 was used, and her engines showed an increase of 2 h.p. over coal, while the consumption of oil amounted to 3·94 lbs. of oil per horse-power per hour. This same system was employed on the locomotives of the Chemin de Fer de l'Est, where 22 lbs. of oil evaporated 240 lbs. of water, compared with 22 lbs. of coal briquette evaporating 176 lbs. of water.

The year 1868 also marks another epoch in the progress of liquid fuel, for in it Admiral Selwyn made his now historic experiments with a burner which he himself devised with Aydon, one of the joint inventors of the burner invented three years previously by Aydon, Wise, and Field. These experiments are noteworthy in that they were carried out with the sanction and under the direction of the Admiralty. The burner was a nozzle-sprinkler, and was undoubtedly the most efficient introduced up to that time. Before describing this among others, this brief review may be concluded.

By this time the primitive form of liquid-fuel furnaces had practically gone out of use, although as late as 1878 an oozing furnace was introduced by Paterson in New Jersey. The spray and jet had come to be recognised as the only efficient forms of burners, although these had many variations and were applied in different ways. In 1870 came the Lenz burner, which was used extensively on the Caspian Sea and the Volga. An improvement was made in this later, which provided a circular opening for the oil instead of a flat one, and the tongue was also altered in such a manner that a broader flame was obtained. In 1872 Körting invented a burner which also underwent considerable modifications four years later, and in 1874 Professor Urquhart introduced a burner for adoption on the Russian railways, but this early form was soon dropped on account of the large consumption of oil involved, and about the year 1883 a new type was introduced, which was fitted to a very large number of Russian locomotives. In the year 1880 the Brandt burner (fig. 3) was introduced, and good results were obtained, though its chief disadvantage was that,

when cleaning was necessary, steam had to be shut off, which was an expensive and often inconvenient task.

The burner of Aydon, Wise, and Field is one of the earliest methods of burning petroleum as fuel, and was first used at South Lambeth in 1866 with a Cornish boiler. The oil entered from a vertical pipe through an opening about 1·2 inches in diameter, through which it flowed from a tank above at the rate of about 3·3 gallons per hour. During its course the oil was forced into the discharge pipe by the stream of superheated steam escaping from the horizontal pipe, which drew in air through the funnel. The oil, steam, and air met and mixed in this pipe, and arrived through a cone-shaped mouth over the fire-door into the fire-box. About 3 feet 3 inches from the fire-door was a bridge of tiles against which the stream of oil and steam impinged in the form of a cloud of thin vapour, the superheated steam having distributed part of the oil and vaporised the remainder. The unconsumed particles of this vapour either became ignited at a coal fire or against the fire-bridge, which was intensely hot. This ignition was facilitated by the previous mixture with air. The supply of oil was regulated by a tap in the supply pipe, the steam by a spindle, and the air by a cap. The fire was lighted by placing some red-hot coals on a sheet of iron on the grate, which afterwards ignited the oil.

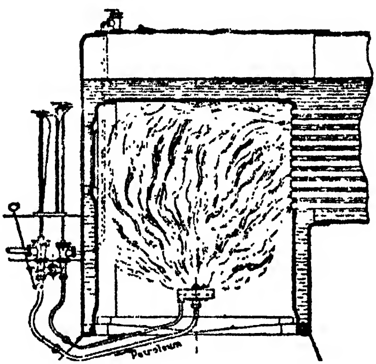


FIG. 3.—Brandt's burner.

The burner of Aydon and Selwyn (figs. 4 and 5) was used in the trials conducted by the Admiralty at Greenwich in 1868 with a Field marine boiler. Aydon modified his apparatus so that the oil and steam met at an acute angle. The steam spray was regulated by a tapering spindle, which was kept in position by a small pressure screw. The pipe in which the meeting of oil, steam, and air took

place remained the same, except that an opening was provided beneath for the admission of air. During the first experiments of Selwyn two fire-bridges were placed in the fire-box and the floor was covered with fire-bricks. Subsequently this brickwork was removed, and the fire-bridge alone remained. A coil of piping was, however, hung between the Field tubes, and through this the steam, being previously superheated, had to pass before it arrived at the sprinkler. The fire-door was removed, and was replaced by a cross-barred slide, by means of which the air was regulated. The results of the trials made showed a 7·5-fold evaporation with coal, against a 10·5-fold

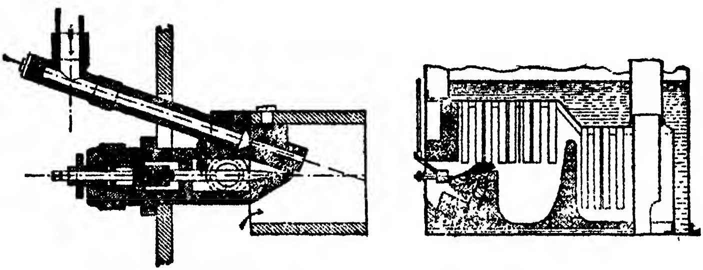


FIG. 4.—Aydon and Selwyn's burner; and Fig. 5, arrangement of furnace.

evaporation with tar residual. The Admiralty were so satisfied with this, that the boiler of H.M.S. *Oberon* was placed at Admiral Selwyn's disposal for further experiments. This had a heating surface of 1707 feet, whereas the Field boiler had a heating surface of only 1063 square feet. For these experiments Admiral Selwyn used a nozzle-sprinkler in which the oil was delivered through a central pipe, and the steam through a concentric pipe. With a view to making the boiler immediately available for coal-firing, the grate was not removed, but was merely covered with fireproof stones, which attained a white heat, and were found excellent non-conductors. For the same reason the steam superheating pipe had to be placed to the forward smoke-box. During a three hours' trial, on November 13, 1868, 2·2 lbs. of tar oil evaporated 33·9 lbs. of water at a temperature of 100½°] with a steam pressure of 40¼ lbs.

The other trials did not show results quite so satisfactory. In trials with water at a temperature of 212° F. the best result attained was an evaporation of 37¼ lbs. of water with 2·2 lbs. of tar oil, the theoretical evaporating power of which is put down at 38·6 lbs. A perfect combustion of the oil was therefore practically obtained.

In the burner of Dorsett and Blythe (fig. 6) the retort and burners were separate. Experiments with this appliance were carried out on board the *Retriever*. When steam was generated the two boilers employed were filled with heavy tar oil of 1·050 specific gravity, and this was evaporated by means of an ordinary coal fire. When the oil vapour reached a pressure of about 20 lbs. per square inch it was conveyed to the retorts of the furnaces, where it entered a couple of burners, which continued the evaporation of the oils. When the oil vapour had attained a pressure of 50 lbs. per square inch, or a temperature of 932° F., it was admitted to the furnaces. About 75 mm. above this a thin iron plate was attached, which extended backwards as far as the combustion chamber. About 75 mm. still higher another plate was placed, shorter and perforated. This was covered with fire-bricks. The back opening between the two plates was filled up with these bricks, the forward part only partly, so that a certain volume of air could enter and find its way through into the furnace. Another volume of air, regulated by means of a sliding valve, was admitted to the combustion chamber between the lower plate and the ash-pan. The gas-supply pipe enter-

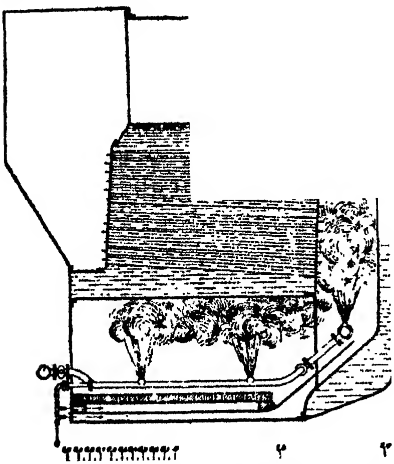


FIG. 6.—Dorsett and Blythe's gas furnace.

ing each furnace ran along the fire-bricks as far as the combustion chamber, and then turned back. The combustion chamber at the back, common to all three furnaces, also contained a gas pipe which communicated with those in the furnaces. The gas pipes in the furnaces had four holes of 0·08 inch in diameter, and that in the combustion chamber had eight such holes, so that the boiler was heated by twenty gas flames. Each pipe had an entrance and a vent tap, the first for regulating the supply, and the latter for carrying off any condensed oil which might form during the heating. In consequence of the very high temperature of the oil vapour, the retort boilers as well as the gas pipes were protected with a jacket of thin iron plating, and the spaces between filled up with sand and pottery. About 150 h.p. was given out by the engine, which means, at an hourly consumption of 529 lbs. of oil, about 3·52 lbs. of oil per indicated horse-power per hour. The evaporation, which was 12·35-fold, according to Paul, agrees with these data. The combustion also seems to have been good, and very little smoke was given out by the steamer.

Lenz's first sprinkler (fig. 7) was introduced in 1870, and was extensively used on the steamers of the Caspian Sea and lower Volga. In this burner two pipes lead to the sprinkler in the fire-door; the upper one conveys the oil, and the lower one the steam. The sprayer is divided into two by a partition A, thus preventing the intermixture of oil and steam. This division terminates in a tapering tongue B, in the grooves of which the oil flows out to be blown into separate thin sprays by the steam that comes out from underneath this tongue. The intervals between the sprays of oil serve to facilitate the access of air. The flow of oil and steam is regulated by the circular slides C C, which are pressed by spiral springs against the inner walls of the cylindrical sprinkler. A spigot fastened eccentrically in the axle of the spindle D grasps each slide. The spindles D are firmly packed at E against the partition, and terminate outside the sprinkler with a square section, so that they can be turned by keys, and thus effect the displacement of the slides. Should the flow of the oil be stopped, the oil pipe is shut off, the tap F is opened, and

the tongue openings are then blown through. When a thorough cleaning is necessary, the cover G is unscrewed. The first Lenz sprinklers were not at all satisfactory, as the flame did not uniformly heat the furnace, and combustion was imperfect, while the walls and ends of the pipes were destroyed. Soot formed in considerable quantities, and a very poor duty was obtained per indicated horse-power per hour, requiring as much as 6·6 to 7·7 lbs. of mineral oils.

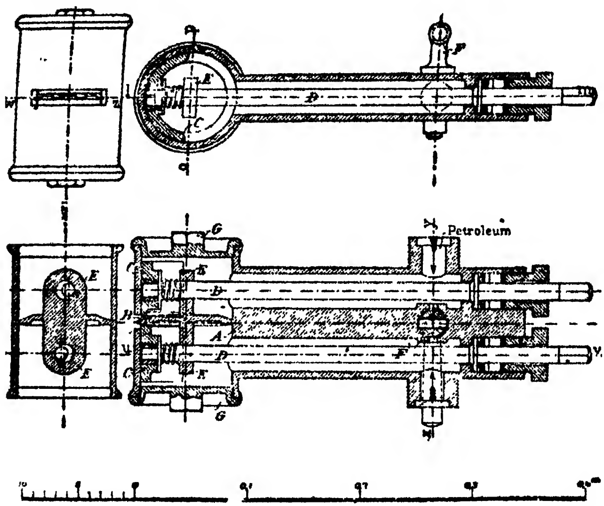


FIG. 7.—Lenz's first burner.

The new slit-sprinkler of Lenz was furnished with a circular opening round the cylindrical chamber, instead of a straight slit. This ensured a circular flow of the oil spray. The slides were also made cylindrical, and were movable backwards and forwards in the chamber. For this purpose grooved eccentric rings were placed round the spindles, and run along a groove in the centre of the slides. The tongue was also altered for the purpose of obtaining a broader flame. This improvement was specially adapted for marine boilers and locomotives, and through its introduction the utility of the Lenz sprinkler

was greatly augmented, although its cost was considerably increased

The nozzle-sprayer of Körting (figs. 8 and 9) was introduced in 1876, and has been used in boilers arranged for coal fires without requiring any change in the fire-box. The non-superheated steam is admitted into the sprinkler by the valve A, and enters first into a well-shaped compartment, from which it escapes into the nozzle through small orifices in the copper tube. This arrangement ensures the liberation of the steam from the deposited water, the volume of which might become very considerable in a small steam pipe only 15 mm. in diameter. The condensed water does not pass out of the orifices with the steam, but remains behind in the bell-shaped compartment, and is drawn off from time to time by means of the screw valve C. The steam flowing through the nozzle induces air through the orifices E, and mixes with it; this mixture vaporises in the mouth-piece F an oil spray 6 mm. diameter, which flows out of the nozzle and is regulated by a tap. The vapour spray and the oil spray meet at an angle of 90°, and, as will be noticed, the flame is blown slantingly into the fire. The air induced by the steam jet is said to produce a better result by being drawn over the oil.

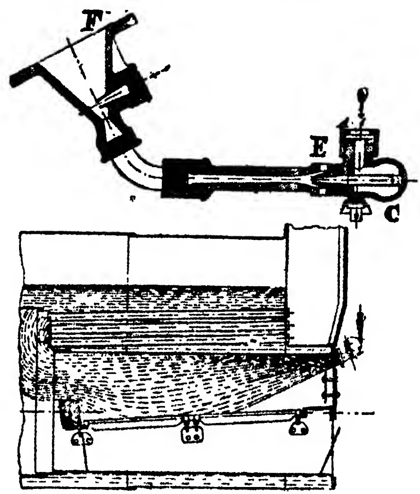


Fig. 8.—Körting's nozzle-sprinkler; and Fig. 9, arrangement of furnace.

Another burner used by Körting, and reproduced in fig. 10, is very similar to that of Aydon and Selwyn,

already described. The oil flows out of the slit-like openings, and is vaporised by steam jets, which meet it at an acute angle. The steam jets, which issue from orifices of from ·04 to ·08 inch in diameter, are together *somewhat broader than when tar was employed. Should the nozzle get stopped up, the plug C is taken out, the supply turned off, and the nozzle cleaned out with the needle D.*

Prof. Urquhart's first liquid-fuel burner was experimented with on the Grazi-Tsaritsin Railway in Russia, but owing to the large consumption of oil involved, the system was for a time relinquished.

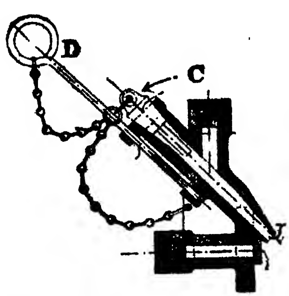


FIG. 10.—Körting's third burner

Between 1882 and 1885 Urquhart's latest nozzle-sprinkler (fig. 11) was introduced. In this the oil is conveyed from the tanks in the tender by means of a tube and a pipe into the burner. The non-superheated steam leaves the dome of the boiler and enters the latter; it passes through orifices into the interior of a bronze spindle, and escapes through the front of the nozzle. A spiral wheel which moves on a spring in a groove regulates the outlets for the oil residuals. To obtain the requisite amount of air the burner is fixed so as to extend into a flue, and a space of about 1 inch is allowed between the flange of the sprinkler and the plate of the boiler. The oil and steam are separated inside the sprinkler by means of a box filled with asbestos packing, which has to be renewed about once a month. The admission of steam is regulated by a special valve in the pipe. Urquhart, after making numerous experiments with these burners in 1884, found that, by using oil for his locomotives instead of coal, a saving of 53 per cent. could be effected. In locomotives burning anthracite, and with a steam pressure of 8 atmospheres, from 7 lbs. to 7½ lbs. of water were evaporated by 1 lb. of anthracite; whereas 1 lb. of oil evaporated from 11·35 lbs. to 12·25 lbs. of water. As a result of this, 143 locomotives were fitted

with this system on the above-mentioned Russian railway as early as 1885.

Should the burner get stopped up, the spindle has only to be screwed back, and the oil will force the carbonised particles into the fire-box. *Urquhart also protected the walls of the pipe against the flames,* and prevented the

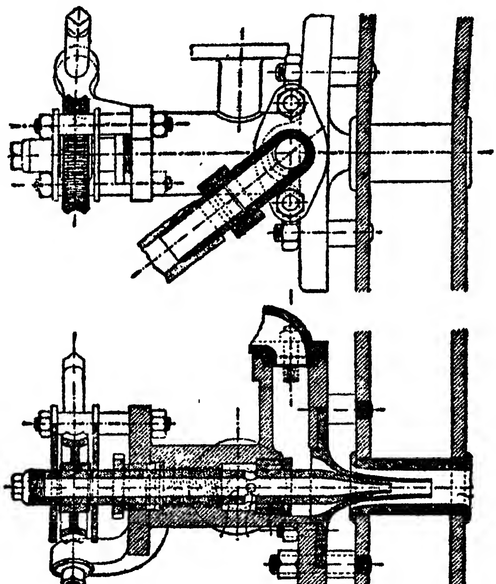


FIG. 11.—Sectional views of Urquhart's burners.

deteriorating effect on the boiler which their direct action would entail, by lining the inside of the furnace (fig. 12) with fire-brick. The sprinkler is fixed rather low, and blows into a furnace chamber built into the fire-box and covered with a vaulted roof which slants off in the direction of the tube-plate. The brickwork stands out from the wall of the fire-box about 2 inches, so that these walls are not lost to the heating surface. The flames beat from the furnace chamber against what was previously the fire-door,

and which has been bricked up, leaving only a peep-hole. Two channels are built into the walls of the furnace chamber, and lead a portion of the heating gases to the lower surface of the tube-plate, as well as into the spaces between the brickwork and the outer walls of the fire-box, so as to give these a larger heating surface. The requisite amount of air is induced into the furnace by the jet, and more air is admitted by the ash-pan dampers, which are regulated by chains and chain wheels. The air entering at the front ash-pan damper passes through a channel. and is warmed before being admitted to the gases. Complete combustion of the oil is ensured by fitting the fire-box with tiles, which, being non-conductors of heat, keep the walls of the fire-box at an equal temperature, and even relight the oil-stream should it have a tendency to become intermittent.

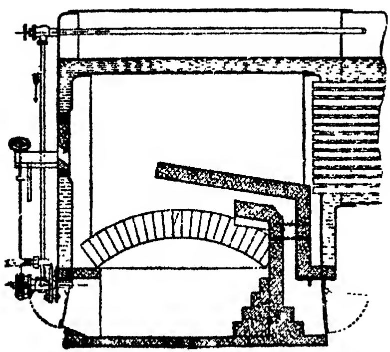


FIG. 12.—Arrangement of fire-box for Urquhart's burner.

The burners introduced by D'Allest, chief engineer of the Cie Fraissinet of Marseilles (figs. 13 and 14), were the outcome of an express wish on the part of the French Ministry of Marine to obtain a burner suitable for use on torpedo-boats. The experiments made with these burners, therefore, form an interesting link in the general development of liquid fuel, while they were probably the most exhaustive which had been carried out up to that time. The first burner consisted of a conical chamber of bronze, to which the liquid was conducted through a tube. Through the chamber into which the petroleum was admitted ran a spindle or small shaft, which was operated from the end by a small handle; the top of this spindle filled the orifice at the mouth of the burner. When drawn back, an annular opening was shown, varying between 0 and 2 mm. Through this annular opening the

petroleum passed into the furnace in the form of a hollow stream. The steam, led to the sprayer through a pipe, surrounded the oil chamber, heating the contents, and,

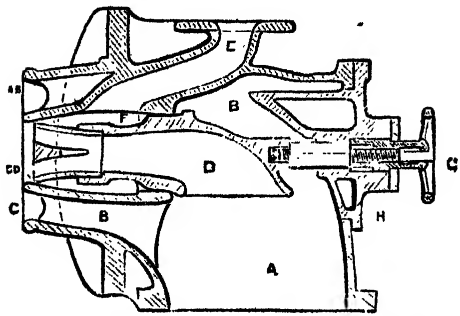


FIG. 13.—D'Allest's burner, using compressed air.

escaping in a stream of cylindrical form, enclosed the petroleum, and reduced it to spray, projecting it thus into the furnace. The force of the fire was regulated by the

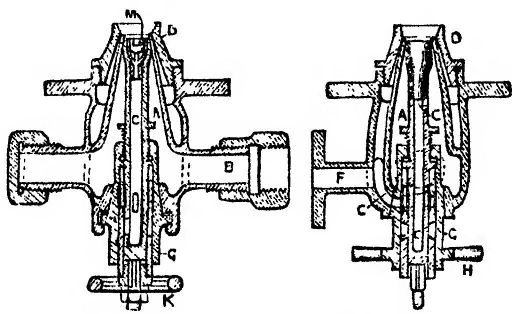


FIG. 14.—Sectional views of D'Allest's burner for use on torpedo-boats.

valve, which could be moved backwards or forwards, either diminishing or increasing the quantity of hydrocarbons introduced into the furnace. D'Allest concluded, as the result of several experimental tests with oil- and coal-firing, that to evaporate the same quantity of water in a unit of time with the same draught, the oil-fired boiler can be

20 per cent. smaller than the coal-burning boiler. Now, a still greater difference has been found in practice, caused by the fact that "*in burning coal there is introduced into the furnace a much greater quantity of air than is theoretically necessary, while with petroleum, on the contrary, this quantity of air is reduced, on account of the intimate union of the combustible and the supporter of combustion,*" and on account of the uniform flow of the two, all which brings the combustion nearer the theoretical conditions.

CHAPTER VI.

STEAM-, AIR-, AND PRESSURE-JET BURNERS, ETC., USED IN LAND AND MARINE BOILERS.

SINCE the year 1883 the progress of oil as fuel has been more rapid than in its previous history, and has been due mainly to the greater attention paid to the engineering problems connected with its use, and to a recognition of the difficulties which had to be removed in order to obtain a good combustion and to prevent the deposition of carbon in the tubes and other parts of the boiler. It was further recognised that the burner is not the only important consideration in the burning of fuel oil, and that the arrangement of the furnace itself meant either a proper utilisation of the heat generated or a waste of energy and money.

It was about this time that the late Mr James Holden turned his attention to the use of liquid fuel for steam-raising, the first kind of fuel employed being the waste tar obtained from the oil gas works at Stratford, for which he devised a special spraying apparatus, that could be independent of any extra brickwork, and be also available for use in conjunction with coal, and ultimately introduced a system by which it became possible to fire a boiler either with coal alone, as ordinarily used, with coal and oil combined, or with oil alone. Such an arrangement, of course, possesses a great advantage, for many purposes, over those where special treatment of the furnaces is required, for, as the ordinary grate remains, steam can be raised with wood or coal, when for any reason, such as a prohibitive price, as now obtaining, for instance, oil may be undesirable.

The earlier form of Holden burner—devised more particularly for locomotive work and again referred to in the

chapter dealing with liquid fuel on railways—consists, primarily, of a coned body AA (fig. 15), to the interior of which the oil fuel is admitted through a specially designed regulating valve BB. Inside the body an annular steam jet D is introduced, possessing a central passage for

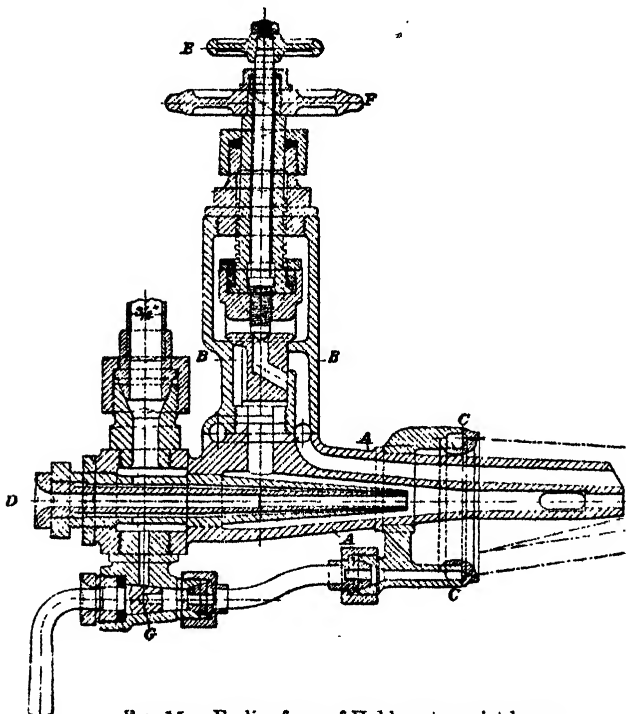


FIG. 15.—Earlier form of Holden steam-jet burner.

assisting in the supply of air, and also for enabling a wire to be passed through the burner without shutting off either oil or steam. At the front, immediately behind the nozzle, a hollow ring CC is attached, and to this steam is admitted and allowed to escape from six very fine jet apertures. The main requirement fulfilled by this steam ring is that the jets induce a strong current of atmospheric air, which is

carried forward and mixed with the spray as it emerges from the nozzle, ensuring complete combustion. The steam supplied to the ring is conveyed through a branch from a small regulating valve attached to the rear of the burner,

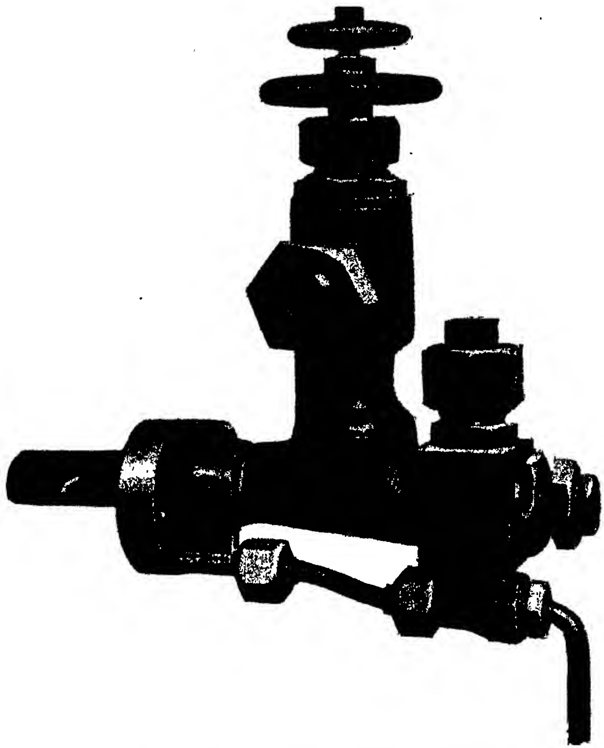


FIG. 15A.—General view of Holden oil injector.

so that only one pipe is required from the boiler; the small jets in the front of the ring are at such angles as have been found to most thoroughly split up the oil.

The valve BB used for regulating the flow of the oil fuel is of special construction, and in the Holden burner a small reservoir of oil is formed by the body of the valve,

a tube with a slit in it being moved up and down inside. With this valve very fine adjustments in the flow of the oil fuel are possible.

In the case of the burners adapted to stationary boilers the main supply of fuel is first admitted by turning the wheel F. Should an increased quantity be required, it is provided by opening the valve actuated by the wheel E, and as the fuel issues from the hole on the top of the nozzle it is atomised by the steam from the ring and centre cones. By this arrangement a larger portion of oil fuel can be injected, sprayed, and atomised without increased con-

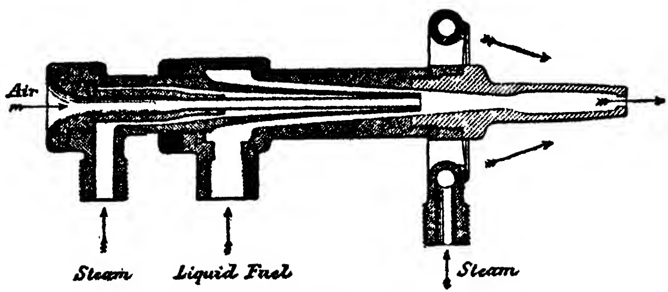


FIG. 16 —Explanatory diagram of Holden steam-jet burner.

sumption of steam. The steam supply to the ring on the injector is regulated by the small cock G.

In the latest form of the Holden steam-jet burner, illustrated by fig. 17,[1] the spray is projected from a series of holes *d* arranged at a slight angle, so that the streams of atomised mixture shall converge as shown at *y* after leaving the mixing chamber. Instead of the outer perforated nozzle ring C as used heretofore (figs. 15–16), steam in the improved burner is projected from a series of holes *e* from a chamber limited in width to that of the mixing chamber, and is supplied by a pipe *t* from the main supply entering at *s*; the oil, which enters under slight pressure along the pipe *p*, is controlled by a screwdown valve *v* and wheel *r*, in its passage to the base of the outer cone *n*, along which it is drawn by an annular steam jet supplied at

[1] *Engineering Review.*

about 60 lbs. pressure to the inner cone k; this steam jet also induces a jet of air from a by way of the central tube, from which, and the general construction, it will be seen

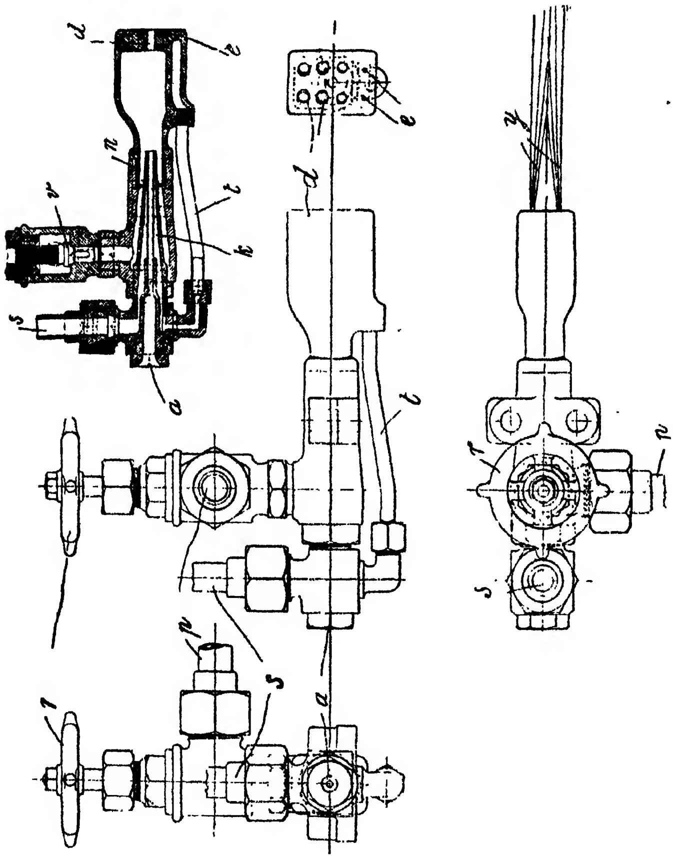


FIG. 17.—Elevation, sectional, and plan views of the latest form of the Holden steam-jet burner.

that this burner is an inside mixer and belongs to the injector class—*i.e.* the oil and atomising agent meet inside the burner, and the oil is induced by the steam.

Of burners that have been specially devised for boiler work, there is a great variety of forms of each of the three

principal types, known as steam-jet, air-jet, and pressure-jet burners; to which may be added such other variants of these types as burners in which both steam and compressed air are used for atomising the fuel, and burners in which compressed air is used in combination with a mechanical or pressure feed. Of these, all but pressure-jet burners (which, by the way, are always outside mixing) may be constructed for the oil to be atomised either before or after it leaves the burner.

Burners may be further characterised as *atomising* when the oil is swept from the nozzle by a steam or air jet; as *chamber*, when the oil mingles with steam or air within the burner and the mixture issuing from the nozzle is broken into minute particles by the expansion of the steam; as *drooling*, when the oil oozes out on to either a steam or air jet; as *injector*, when the oil is induced by either a steam or air blast; and as *pressure spraying*, when the oil is atomised by mechanical means and without the use of a steam or compressed-air blast.

As now more generally practised, the use of steam-jet burners is confined principally to stationary and locomotive boilers; air-jet burners to melting furnaces, owing to their higher temperature; and pressure-jet burners to marine boilers. The two more important features that should be embodied in all burners, for whatever purpose required, are: (1) easy method of installation; and (2) a construction that facilitates speedy inspection, cleaning, and renewal of such parts as may be subject to wear.

In describing first a few typical examples of steam-jet burners, and taking these in the order named:—That known as the "Best" may be cited as one of the most extensively used of the atomising class. In this burner (*vide* fig. 18, and figs. 91–93) the steam meets the oil at right angles from a narrow slot-shaped nozzle, thus atomising externally; this burner is principally used on locomotives and is further described in Chapter X. Another of this class is the Frugoni burner (used on the U.S.A. battleship *Delaware*); in this, as will be seen by the illustration[1] (fig. 19), the construction is very similar, the spraying being external through slot nozzles arranged at right angles. Others of the outside atomising class that may be mentioned are the Körting

[1] *The Engineer.*

steam-jet burner; the Rockwell; the Oil City Boiler Works (fig. 55); and the Rusden-Eeles, which is a burner formerly largely employed on the vessels of the Shell line of steamers; in this (*vide* fig. 20), the oil is heated in a tubular chamber

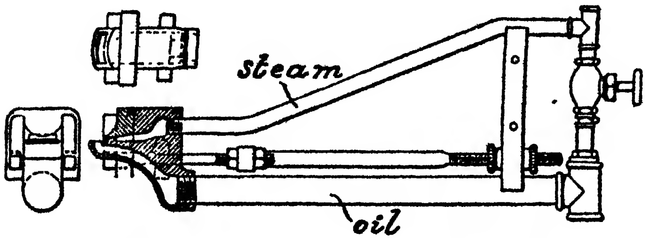


FIG. 18.—Section of locomotive type steam-jet burner (Best).

jacketed on both sides, and as the burner—which is of the external mixing type—is constructed to allow of separate adjustment of the steam and oil jets, the consumption of the fuel can be easily controlled to suit running conditions.

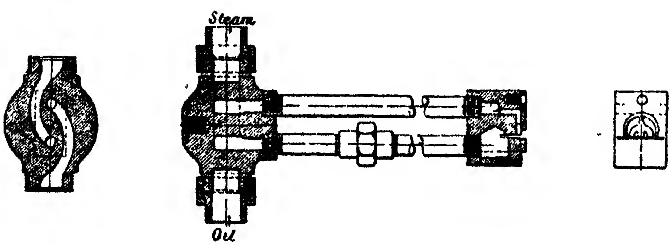


FIG. 19.—Frugoni steam-jet burner.

A steam-jet burner is also used by the Anglo-American Oil Co. at their refinery works, Purfleet, known as Winters', which is not dissimilar to the one just described, only differing, in fact, in the manner of regulating the feed of the oil, which is effected by a simple form of pin valve. The burner is of unusual length and steam-jacketed, the steam being superheated to a high degree by means of a pipe passing through the furnace. The flame impinges on a brick baffle 18 inches square, situated 3 feet in from the

burner and about half the height of the furnace. Besides these, there are the Bellon and Waure steam atomiser burners, now being tried on the Paris, Lyons, and Mediterranean railway engines. Of these, the former has a central oil nozzle, and the jet is atomised by an annular steam jet; in the latter the oil nozzle is annular, the jet being atomised by a central steam jet.

Of steam-jet burners of the *chamber* class, the Hammel

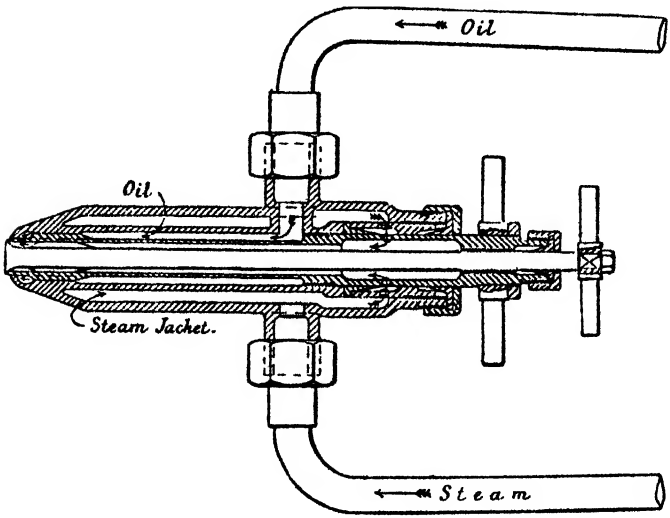


FIG. 20.—Rusden and Eeles' burner.

is perhaps the most widely used. This burner, as will be gathered from the illustrations, figs. 21 and 21A, is of the type also known as an *inside mixer*—*i.e.* the steam jet is brought into contact with the oil jet inside the burner. In form, this burner resembles to a certain extent the "Best" (*vide* figs. 18, and 92–93), in that the jet is projected in a thin horizontal stream from a narrow slot-shaped nozzle, but differs from the slot burner illustrated in the manner of its operation, *e.g.* the oil enters at A and flows through B into a mixing or atomising chamber C, situated above the steam jet. After flowing through F and

E, the steam impinges on the oil contained in the mixing chamber C, from three small slots G, H, and I. The mixing chamber is fan-shaped, and consequently causes the jet to spread over a considerable area. This burner is also constructed with renewable liner plates KK, and is therefore adapted for oils containing grit and other matter in suspension without being filtered; the renewable plates constitute a practical if simple improvement, but, apart from this con-

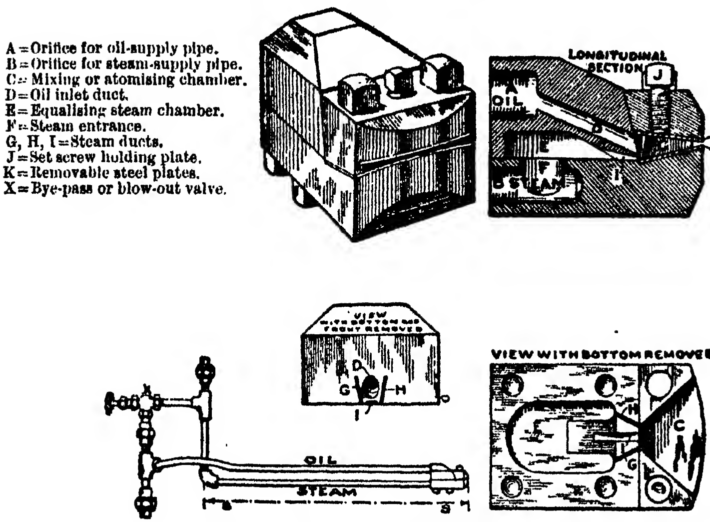


FIG. 21.—Hammel steam-jet burner.

sideration, steam at high velocity is well known to cause considerable wear on the surfaces in contact. The Hammel burner is usually arranged at the front end of the fire-box, as shown in fig. 21A, in order to project the flame at first away from the boiler tubes, by which means the flame can be projected on to a fire-brick lined wall at the front, thus enabling combustion to be complete before contact with the boiler tubes, and for the burners to be arranged lower down, but is obviously not adaptable for all oil-burning systems, nor indeed for any other than a steam-jet burner of special construction; this method, however, has been

adopted for locomotives by the Southern Pacific Railway (*vide* figs. 93 and 97). When fitted up on the Hammel oil-burning system, as shown, some surprising results have been obtained—*e.g.* with a 500 h.p. Stirling boiler, rates of evaporation equalling from 14·25 to 15·3 lbs. per pound of oil from and at 212° F. have been obtained, which

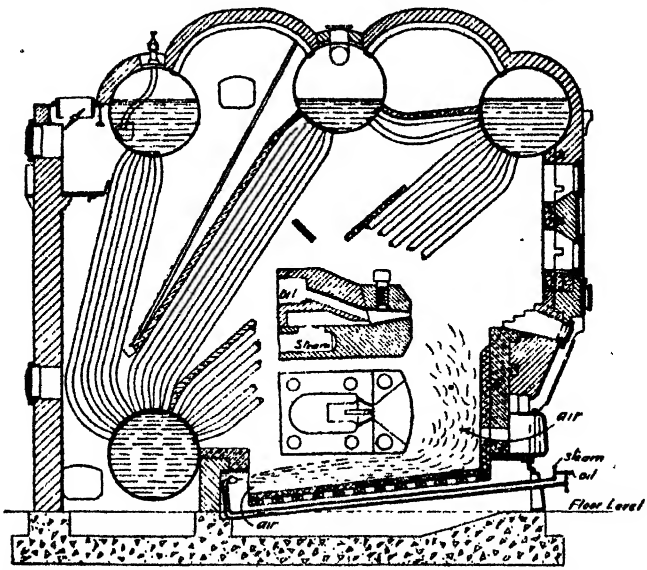


Fig. 21A.—General arrangement of the Hammel oil-burning apparatus applied to a Stirling boiler, with insets showing sections of one of the two steam-jet burners used.

is much in advance of the usual performance of a steam-jet burner. But whether these results are due to the particular disposition of the burners is not clear, as the burners are capable of atomising the oil with a very low percentage of steam, judging from the results obtained in a series of tests carried out by Prof. Cory, of the University of California, ranging, in fact, not higher than from 2·1 per cent. to 2·7 per cent. of the water evaporated—viz. 228,097 and 149,581 lbs. respectively on Los Angeles oil (having a specific gravity of 0·977 at 60° F., and contain-

ing from 0·4 to 0·8 per cent. of moisture), which, as fired, equalled 16,585 lbs. and 10,577 lbs. respectively. However, it may be found that firing forward from the bridge may be more favourable to this form of boiler than others, as it allows an unusually large combustion space, and for the air to be raised to a considerable temperature on its passage along under the fire floor. It may be stated also that the oil was fed to the boilers under an average pressure of 37 lbs. per square inch, and at a temperature of 140° F.;

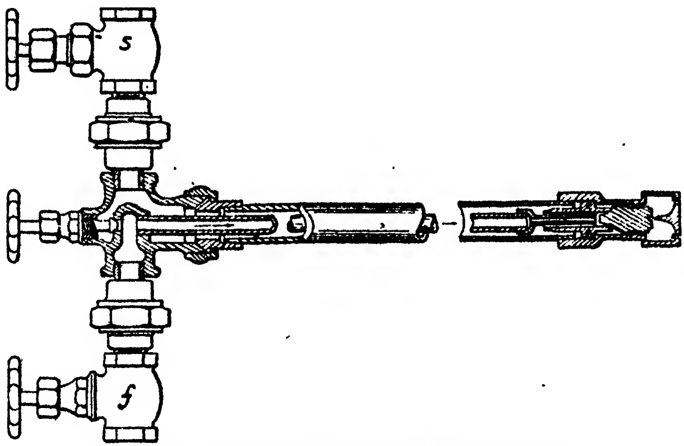


FIG. 22.—Improved Little Giant steam-jet oil burner.

its thermal value as fired being 18,280 B.T.U. per lb., which, corrected for moisture, equals 18,353 B.T.U. per lb. of fuel.

Of the several other steam-jet burners of the *chamber* class, one known as the "Little Giant" (*vide* fig. 22), and, in common with others of this class, inside mixing, sprays from a double long slot with sharp edges. In this burner the oil pipe is surrounded by steam which enters the mixing chamber at the nozzle end, both oil and steam are regulated by ordinary valves *s f*, a third valve being provided for clearing the oil passages from time to time. The Texas burner (fig. 23) is provided with a simple slot nozzle to give a fan-shaped flame, adjustable in thickness by a set-screw. The oil is carried forward by steam to

which a rotary motion is imparted by a short helix; the mixture then passes along a comparatively large mixing chamber containing for a part of its length a spiral. In the Schurs burner (fig. 24)—also used for melting furnaces and the like—there are two atomising points; the first, *a*, breaks

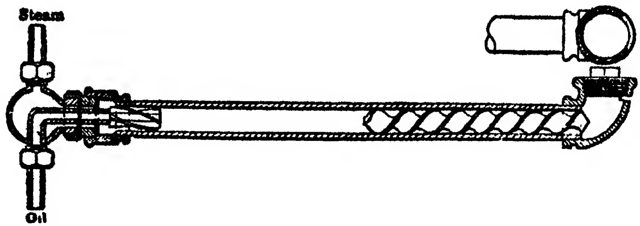


FIG. 23.—Texas steam-jet oil burner.

up the oil and steam into a fine spray, which, after traversing the vaporising chamber *b*, is caused to issue from a nozzle *c*, and in so doing to induce a restricted flow of air from the orifices *d*. In another of this class, and known as the Wilton, the oil is regulated by a drip feed to a cup,

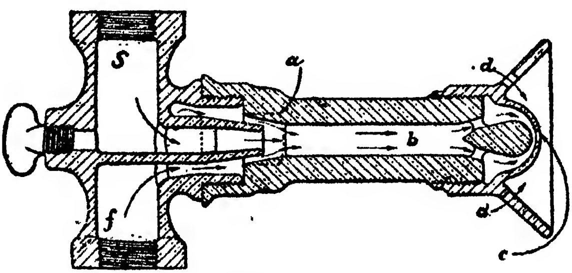


FIG. 24 —Schurs steam-jet oil burner.

and is carried forward by a small steam jet along a jacketed mixing chamber (provided with a helix) to a comparatively large nozzle, around which is located a second narrow annular nozzle for a further supply of steam, a peculiarity of this burner being its quiet action.

The next class of steam-jet burners to be considered is one characterised as *drooling*; in these the oil oozes, drools,

or drips from an orifice on to a steam jet and is carried by it into the furnace. Under this category may be included the burner illustrated by fig. 25, devised by Mr H. G. Garratt for use on the Lima Railways, Peru, which is interesting in that it is readily detachable, so that, in the event of the supplies of oil failing, coal can be used. In this system—again referred to in Chapter X.—the burner is fixed behind a hole in a plate covering the fire-door opening. The spray is induced by an annular jet of steam at B, which is controlled by sliding lengthways the sleeve A; this burner is therefore an inside mixer. The

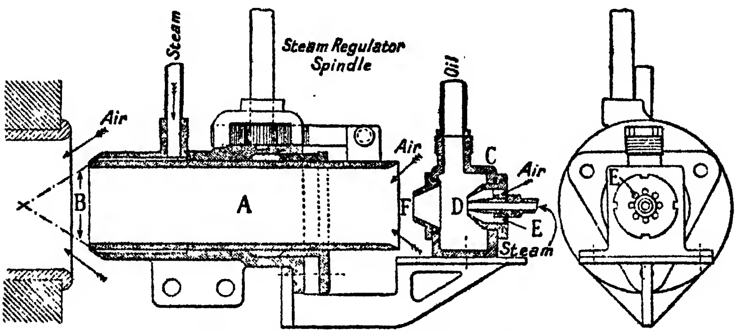


FIG. 25.—Drooling steam-jet burner (Garratt).

oil is fed into a chamber C, of such a size and design as to be practically unchokable; the feed falls on to the combined steam and air jet D, the air entering by the series of small holes E. At F the atomised oil is mixed with a further supply of air, and at B with a third supply of air, which produces a colourless exhaust at the funnel.

In the Peabody burner, another of this class, but outside mixing, a fan-shaped flame is produced. The illustration, fig. 26, shows this in some detail, including an oil strainer, bye-pass for blowing out oil passages, jacketed oil pipe, and removable burner tip. This tip or nozzle contains two very narrow slots separated by a diaphragm, the lower slot for steam and the upper slot for oil, which falls at right angles upon the steam jet. It will be noted that the nozzle is held in position between the jaws of the burner tip by a

single bolt, and can thus be quickly removed for cleaning. In the Gem burner, also of this class and outside mixing,

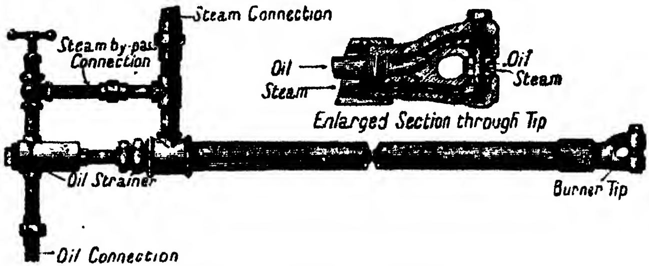


FIG. 26.—Peabody steam-jet oil burner.

the spraying is aided by centrifugal action from an internal screw and cone, and issues from a rose nozzle. Another,

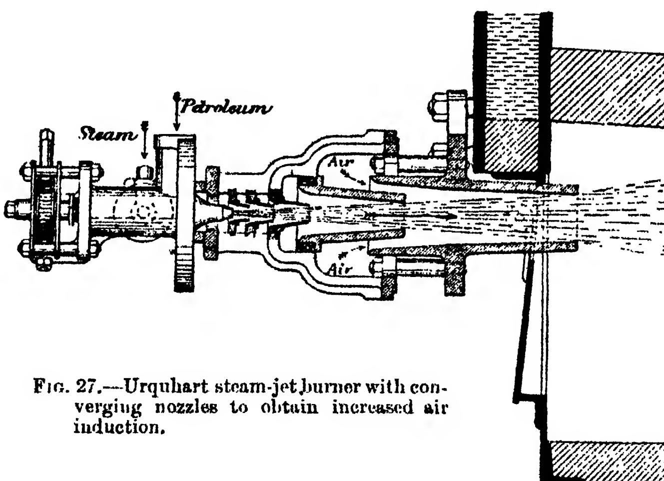


FIG. 27.—Urquhart steam-jet burner with converging nozzles to obtain increased air induction.

known as the Gilbert, is also of very similar construction, but more particularly adapted for metallurgical furnaces.

The Scarab burner also belongs to the drooling class, the oil in this being fed on to a flat spreader, whence it is carried forward and atomised by a blast of steam.

In burners of the *injector* class, the oil and steam or

compressed air first mingle within a contracting conical passage, and are then usually expelled through a flaring mouthpiece. Such burners can be arranged to draw the oil as well as an auxiliary supply of air to the mixing chamber, and are very extensively adopted in this country and abroad. In Russia, where injector burners are the standard type, the Urquhart steam-jet injector—one of the

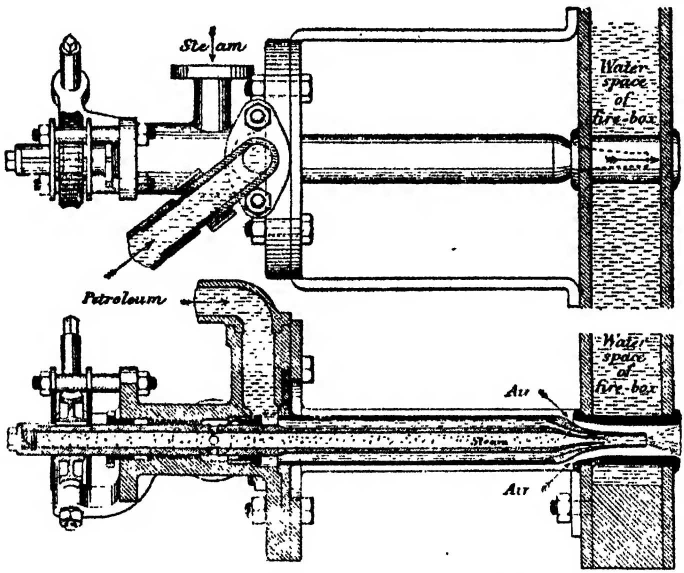


FIG. 28.—Plan and elevation of Urquhart improved steam-jet burner.

first of its kind—is still the most generally used. In its earlier form, this is described in Chapter V. (fig. 11), and in later forms is again referred to in its application to locomotive boilers (*vide* figs. 88 and 89, Chapter X.).

As will be seen from the illustrations, figs. 27 and 28, which represent two of the many modifications used by Urquhart on the South Russia Railways, the burners in important respects resemble Holden's, in that both use a central steam jet and an annular oil jet, but differ from the latter in having an induced air supply surrounding

the oil jet in place of a second annular series of steam jets, as used by Holden. In the improved Urquhart burner (fig. 28) the oil is heated before spraying, and is surrounded by only one air cone.

In both designs the steam nozzle is adjustable laterally by a worm gear to regulate the fuel supply, the steam for the jet being controlled by an ordinary stop valve.

In fig. 29, a Kermode burner of the injector type is shown specially adapted for being worked by steam, the necessary air being induced and the oil fed by gravitation, as in the hot-air-jet system of this make. The manner of its application to a stationary water-tube boiler (Stirling

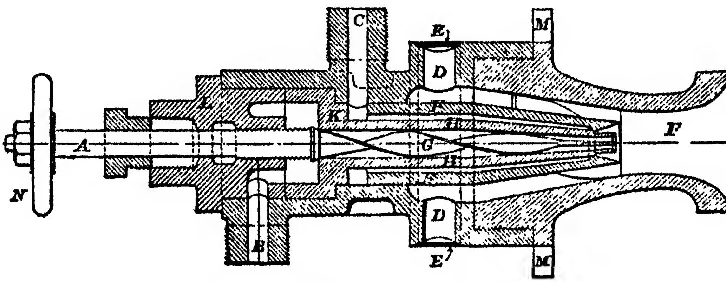


FIG. 29.—Kermode steam-jet burner.

type) is illustrated by fig. 29A, in which it will be seen that there are two burners for each furnace.

In the Kermode steam-jet burner the oil enters the burner through the branch B, and has a whirling motion given to it by the prolonged spiral stem of the valve spindle G, the amount of oil being governed by the hand-wheel N at the end of the spindle A. The steam enters at C around the hollow cone H and passes through slots in the cylindrical portion of this cone, where it fits the inside of the hollow air-cone F. It will be seen that in this way the whole of the oil passing through the burner is steam-jacketed. The air-cone F is also fitted with spiral guides, and the air is drawn past these guides through the openings D by the inductive action of the steam. The amount of air passing may be regulated by means of the movable perforated strap E. On the front portion of the burner is the part

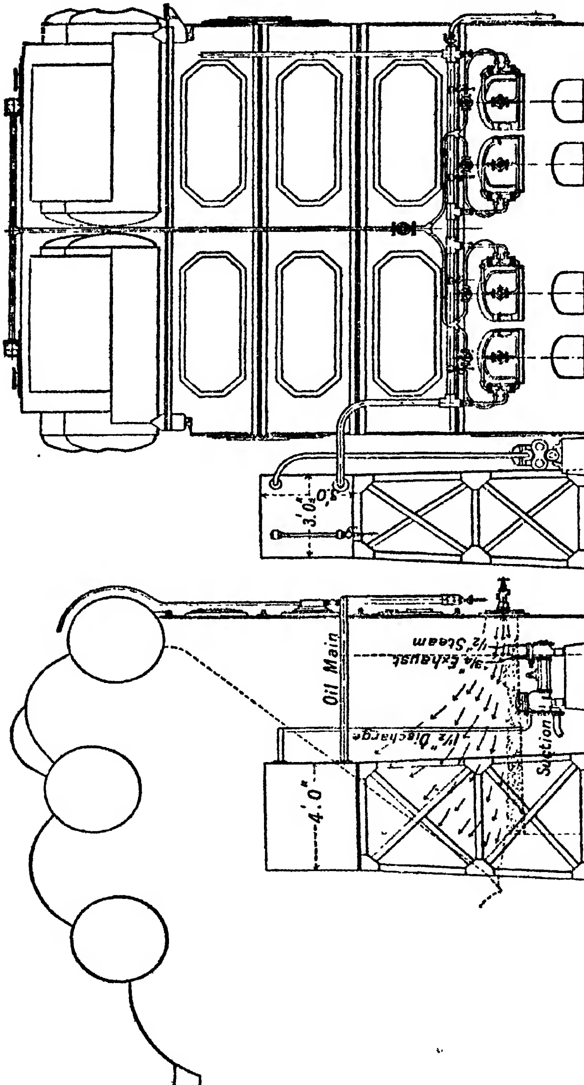
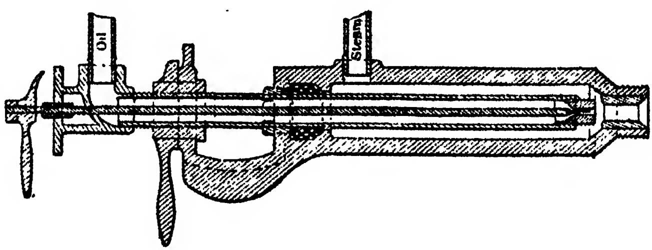
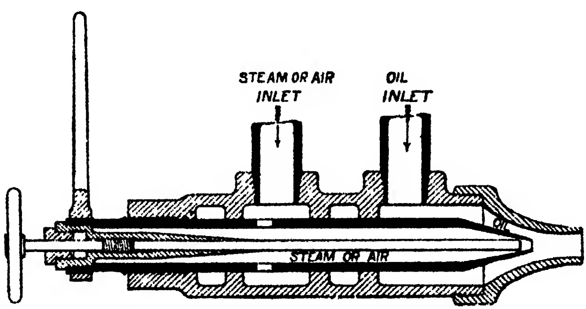


FIG. 29A.—Stirling boiler, shown fitted with oil-burning apparatus on the Kermode steam-jet system.

marked F, which is so arranged that it can be screwed in or out as a whole, being turned by the spider M. When moved, it carries with it the cone F, and in so doing regulates the space between this and the oil-cone H for the escape of the steam. As the range of adjustment is large, the same burner may be used for different powers within wide limits. When the burner is started, the steam opening





Figs. 30 and 31.—Sections of the Kirkwood and Herreschoff steam-jet burners.

is first adjusted by trial, which is done by unscrewing the front of the burner, so that the space between the cone H and that marked F allows the minimum amount of steam required for pulverisation to pass through. The amount of opening for induced air is readily determined by the character of the flame and the sound of the fire when in operation. The flame should be transparent and of an intense white colour, or approaching pink when using light oils. The steam-jet burner may be operated by means

of steam or air, and in the case of this burner, as well as that of the air-jet burner, no alteration of the furnace, as arranged for coal, is necessary. When oil is to be the only fuel used, however, there is no object in fitting fire-bars, and a suitable arrangement of brickwork is provided. Kermode steam-jet burners are also adaptable for utilising as fuel the by-product (tar) from Mond-gas plant, for the boilers which supply the necessary steam; the equivalent evaporation from and at 212° F. obtained averaging 14·65 lbs. of water per pound of tar burnt.

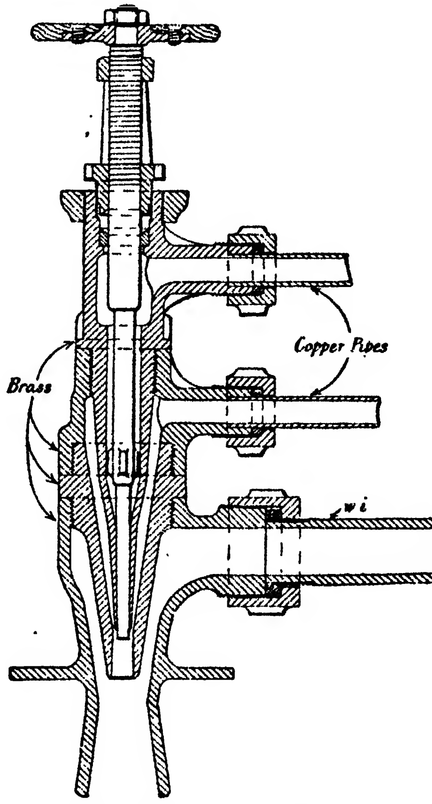


FIG. 32.—Orde's steam- and air-jet burner.

Other steam-jet burners of the injector type are the Kirkwood, illustrated by fig. 30, in which both the oil and steam valves seat at the nozzle end of the burner, and equipped with indexes conveniently indicating the amount of oil and steam turned on; the Herreschoff, which resembles to a certain extent the Urquhart, in the arrangement of the nozzle cones, differing only, in fact, as shown in the section fig. 31, in the use of a central spindle for regulating the steam supply. Under the injector class of burners there may also be included the

Orde combined air- and steam-jet burner described below, and the Reed air- and steam-jet burner (fig. 57) described in the following chapter.

In the Orde combined air- and steam-jet burners as fitted by the Armstrong-Whitworth Co. for steam raising and other purposes (*vide* figs. 32–33), oil is supplied under pressure through the upper of three pipe connections; steam, superheated to 600° F., through the middle connection; and heated air at atmospheric pressure by the lower connection.

In the more recent design of the Orde combined steam- and air-jet burner (*vide* fig. 33), the form and disposition of the nozzle is slightly changed; there is also, it will be noticed, the addition of a branch (*t*) for the purpose of being able to utilise steam pressure to blow through the oil service pipe after closing down, that any obstruction or deposit that may have lodged might be cleared out. As in the earlier design, the annular steam jet in this burner is controlled by a rotary movement of the hollow valve (*v*), and that of the oil—which is preferably heated and supplied under pressure—is controlled in a similar manner by a movement of the needle valve (*n*). During some experimental tests made with this burner at Walker Shipyard some time ago, data as follows were obtained by Mr E. L. Orde, with a stokehold pressure limited to 4 inches of water:—

Lbs. of water evaporated per lb. of oil and at 100° C.	13·3
Lbs. of water evaporated per square foot of heating surface	11·64
Lbs. of oil burned per hour per cubic foot of net furnace space	18·7
Air pressure in stokehold	2" to 4"
Smoke on Ringelman's scale	0 to ½

The boiler (*vide* fig. 33A) upon which these experiments were carried out was of a modified Yarrow type, the fire-bars being kept in place and covered with broken fire-brick to a depth of some 2 to 3 inches. *N.B.*—The temperature of the furnace seldom exceeded 1100° C. at the front and 1000° C. at the back of the boiler.

The main object in this burner is to obtain smokeless combustion with a heavy rate of oil feed. This is sought by mingling the oil spray with an air supply before it reaches the nozzle, and to force it with a high velocity so

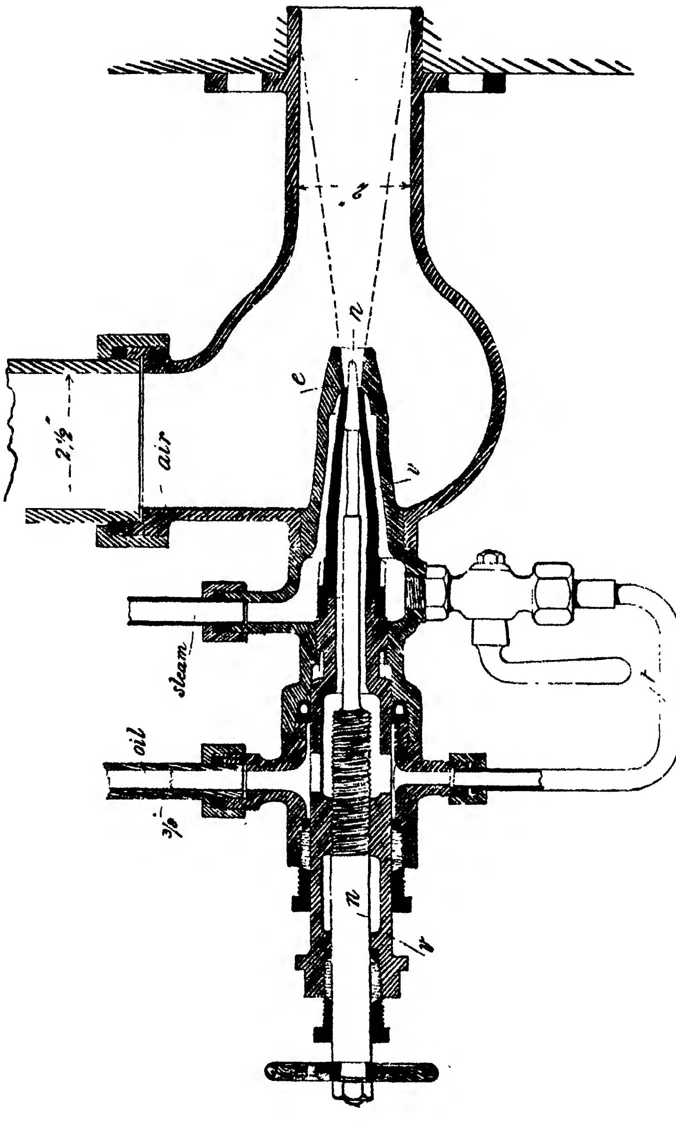


FIG. 33.—Orde improved steam- and air-jet burner.

as to prevent the jet lighting back, and also to compel the flame to traverse the furnace space against deterrent air currents supplied at the sides of the combustion chamber, and through a layer of refractory material covering the fire-bars. The disposition of the cone supplying the steam jet is such as to sweep out and spray the oil at a very high

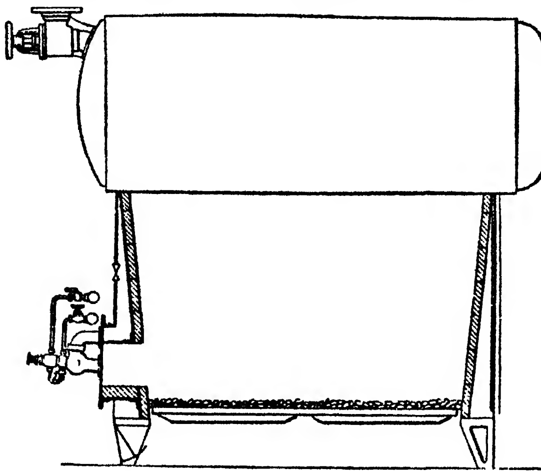


FIG. 33A.—Arrangement of Orde oil-burning apparatus applied to a Yarrow water-tube type boiler.

velocity, thus inducing a considerable current of hot air, which ensures instant ignition of the outer layers of the jet and consequent increase of temperature over the whole flame.

Air-Jet Burners.

The great advantage of steam-jet burners is their simplicity, but as, at their best, they require from 2 to 4 per cent. of the steam evaporated for atomising purposes, and as their evaporative efficiency is seldom higher than 14 lbs. of water per pound of fuel oil, as against from 15 to 16 lbs. with air- and pressure-jet burners, they are obviously not so well favoured for large boiler installations, and are now, in fact, considered to be totally unsuitable for use at sea,

owing to the large amount of make-up water required. Air-jet burners are capable of developing a higher flame temperature than steam-jet burners, and for this reason are particularly adapted for metallurgical work of all kinds (*vide* Chapter XII.).

Air-jet burners are also extensively used for steam raising, both on land and marine installations, but principally for the latter.

Of these, the Grundel burner—also referred to in Chapter IX.—is one of the first to be used at sea, and may be described as follows: In this burner (*vide* fig. 34) the oil, which is heated by a steam coil with live steam, passes

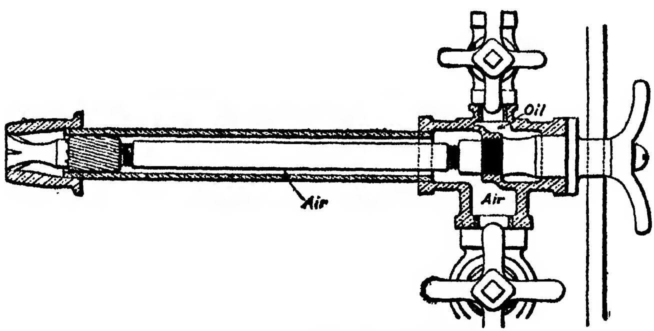


FIG. 34.—Grundel air-jet burner.

through the inside pipe and is diffused radially through a series of small holes. The air, first heated by compression up to 20 lbs., is further heated to a temperature of about 350° F. in the air chamber surrounding the burner, called the air superheater. Air can also be used at the temperature at which it leaves the compressor. The air supply at about 350° F., and at a pressure of about 20 lbs., surrounds the oil pipe in the burner and passes axially along the pipe until near the end, where it has a whirling motion by being caused to flow through small helical passages arranged like the rifling of a gun. It crosses axially, and, whirling through the fine oil streams spurting radially from the end of the burner, breaks up the oil into fine spray. A further air supply (cold) is admitted through the hinged door of the

ash-pan, and is directed up across the path of the flame and heated by a curved fire-brick wall built in the ash-pan close to the front.

The principal difficulties at first encountered with this burner were in the regulation of the supply of oil to the heaters by the pump, and the consequent variation of the temperature of the heated oil, and the freedom of flow through the burners. When the oil is heated too high (above 150° F.), some of the volatile gases are given off and mingle with the air pressing on top of the oil in the heater, and thence flow with the air into the air superheaters and burners, with the result that a heater may get overheated by pre-ignition from this cause.

The superior economy of burners capable of effecting complete combustion without the use of steam as the atomising agent are obvious, as steam, having a higher specific heat value than air, not only absorbs a greater amount of heat, but, being a non-supporter of combustion, has exactly the same effect on evaporative efficiency as the supply of an excess volume of air. It is, of course, unnecessary to add that for sea-going conditions the waste of a weight of steam equal to 2 to 4 per cent., and in some bad cases even as much as 8 per cent., of that used for power, as required to break up the oil when fed under gravitation pressure only and without compressed air, is a great drawback, seeing that all this steam must be made good from fresh-water evaporators.

But as to the superiority of the air-jet over the pressure-jet burner, when applied for steam raising under equally good conditions, the difference, one way or the other, is not very great, and, judging by the significant fact that both systems are in use in the British Navy, augurs but little superiority of economy of the air-jet burner over that of the pressure-jet; and what little there is may be offset by the greater space occupied by the compressing plant for the former, than by the oil pump and heater necessary for the latter. Accordingly, in order to meet all conditions of working, including the ever-present bias of the engineer, Mr Kermode, for one, supplies burners constructed to operate upon either system.

In fig. 35 is shown a section of this make of burner

arranged to be worked by an air jet, in which oil enters by gravitation by the inlet A, and is regulated by the spindle valve D. The supply of compressed air previously heated enters at B and C, that entering at C mixing with the oil spray controlled by E. The air can be regulated at two points, one by the pinion L, which moves the internal tube over the oil nozzle, and the other by the second pinion M, which adjusts the opening of the outer tube or sleeve against the casing J. A general arrangement of three pairs of burners of this make is shown applied to a water-tube boiler (fig. 35A) arranged for coal- or oil-firing, the burners being fixed to the fire-doors and provided with swivel connections for the oil and air supplies.

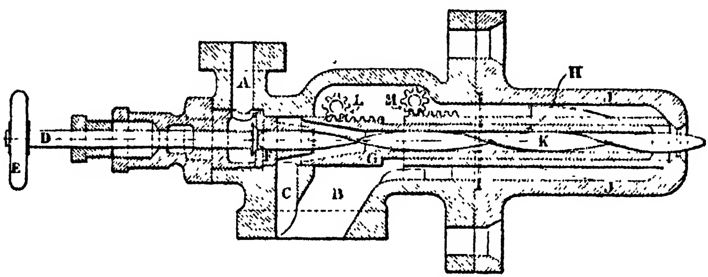


FIG. 35.—Kermode air-jet burner.

The Lassoe, shown in fig. 36, is another very successful type of air-atomising burner, but in this case the air pressure is very low, only about $1\frac{1}{4}$ lbs. per square inch, and the atomising is accomplished by a series of small spirally drilled holes, about $\frac{3}{8}$ inch diameter, which seem to have a marked effect in producing a short flame. The oil supply is delivered through an orifice about half the diameter of the air holes, and is delivered under a pressure of about 15 lbs. Steam can be used with this burner, but low pressure is preferred.

The air pressure is supplied from a rotary blower, and the oil from a pump, this being regulated by a pin valve, the position of which in later designs is adjusted against an indexed dial and pointer. This burner is used on steamers plying between the western coast of America and Japan,

and has worked satisfactorily for several years with the thick asphaltum oils as obtained from the Californian fields.

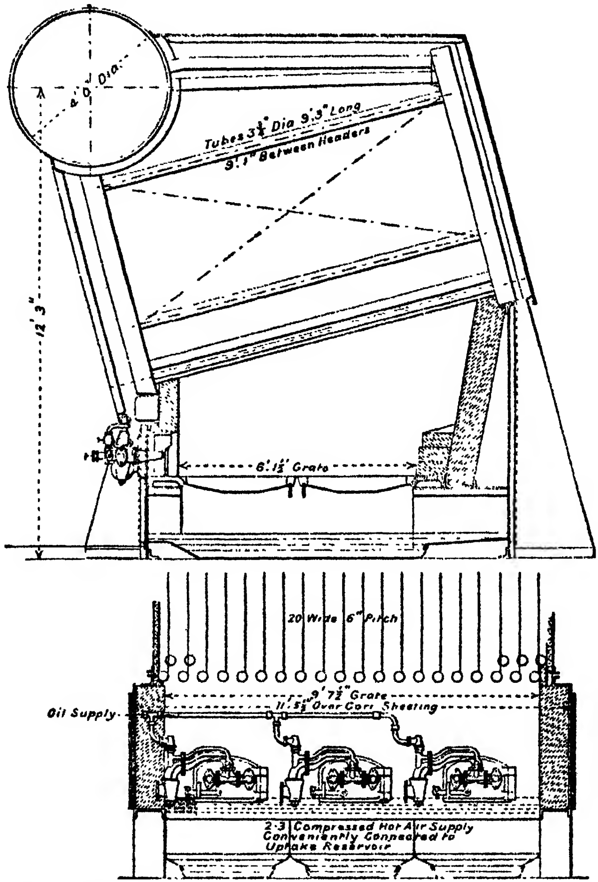


FIG. 35A.—Babcock and Wilcox water tube boiler, arranged for oil-burning on the Kermode air-jet system.

An air-jet burner of somewhat similar construction, and used in the tests made by the U.S.A. Liquid Fuel Board, is illustrated in Chapter VII.; this, known as the Oil City

Boiler Works air-jet burner (*vide* fig. 54), is arranged with cone seated valves for the air as well as the oil supply. In

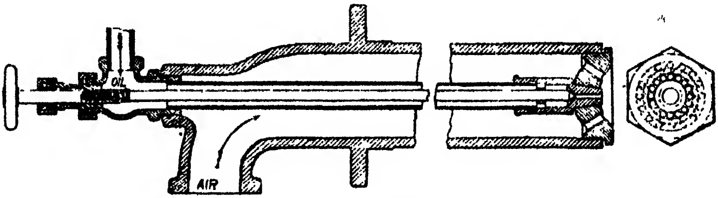


FIG. 36.—Lassoe air-jet burner.

addition to the foregoing, other air-jet burners, such as the Brett, Hoveler, and Stackhard, described in Chapter XII., are applicable for boiler work.

Pressure-Jet Burners.

For oil-firing on the pressure-jet system, this is supplied to the burner at a temperature of about 200°, and at a pressure of about 100 lbs. per inch, both varying according to the viscosity and flash point of the oil used. The

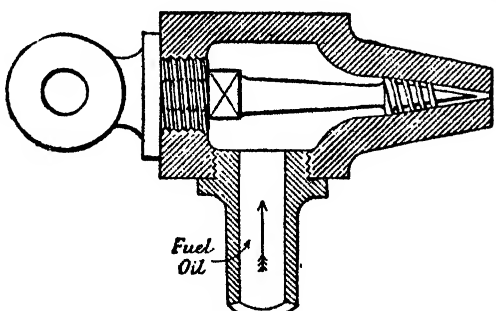


FIG. 37.—Diagram of Körting pressure-jet burner.

Körting burner (fig. 37) is probably the first to work successfully on the pressure-jet system, *i.e.* by the simple method in which the pulverisation of the fuel is direct, the oil being forced merely by pressure through the burner. The oil is first heated to a temperature of 130° C., and then

is forced through the burner under a pressure of 60 lbs. or so. The oil is pumped into a chamber feeding the jet, and this jet is, as will be seen from the accompanying sketch, fixed to a spindle carrying a spiral screw. The oil is forced down this spiral, acquiring a vortex movement, which sprays it out of the jet in a very finely divided state, and of sufficient intensity to make it fly into spray by centrifugal force as soon as it issues from the nozzle, this action being materially aided by reason of the oil issuing at a temperature above the boiling point.

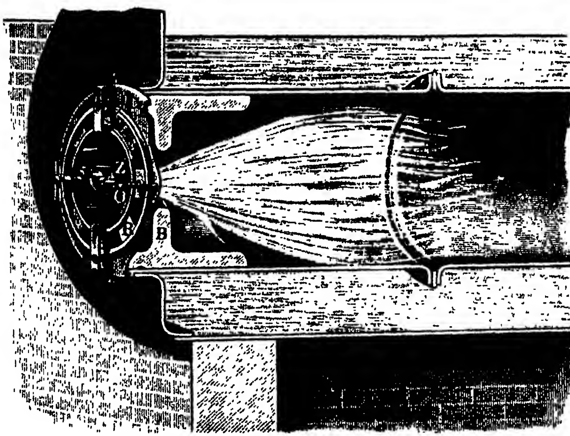


Fig. 38.—Körting pressure-jet burner fitted to Lancashire boiler.

The action of the Körting pressure-jet burner, as illustrated in the sectional view, fig. 38, shows clearly the centrifugal effect resulting from the rotary movement imparted to the spray, this vortex action having a far greater effect with pressure-jet burners than with either the air- or steam-jet variety. In this burner air induced by the spraying of the oil jet from the burner (Z) is drawn through openings (L), which can be regulated by a rotary movement of the slide (R). A fire-clay lining (B) is fitted to protect the furnace front from the heat of the flame.

Another and more modified design of burner is the Swensson (fig. 39). The fuel in this burner is forced

through a minute orifice, and is thereby divided into a finely divided spray by striking against a cutter placed at a short distance from the orifice; the cutter has a diamond form, and by this means breaks up the spray in a very satisfactory manner, under suitable conditions of pressure and temperature. It will be seen that in the construction of this burner, true alignment of the spray valve is assured by arranging for this to be separate from the feed adjustment spindle, the valve itself being short and held in a guide extending to nearly its full length; also to ensure nicety of adjustment and to prevent the point and the spray aperture from being damaged by too great a pressure from the feed spindle, the valve is provided with a shoulder; it also has a spring to cause it move away from its seat in exact accord with the outward movement of the feed spindle.

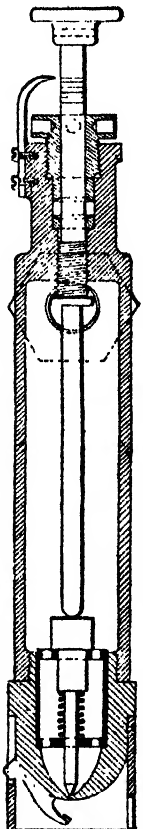


FIG. 39.—Swensson's pressure-jet burner.

In the Meyer pressure-jet system so extensively used for burning oil, each furnace is until quite recently fitted with a quadruple nest of pressure-jet burners, as shown in fig. 40, each furnace being provided with a distributing box having four atomisers *v*, and four nozzle chambers *b*. Each burner (*vide* fig. 40A), consists of an atomiser *v* pressed into position in the nozzle *n* by a spring *s* and end cap *c*, and is also provided at its end with a series of coarse threads by which the oil under pressure is widely diffused in the furnace. The fuel for the four jets is regulated by the

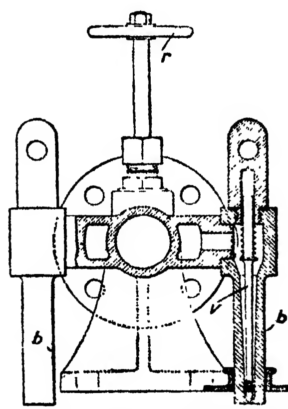


FIG. 40.—Plan view in part section of quadruple set of Meyer pressure-jet burners.

stop-valve *r*, and any excess delivered by the pump is discharged through a spring-pressed bye-pass valve back to the suction heater, so that the stokehold regulation can be carried out without reference to the speed of the pumps, although naturally this latter is regulated under running conditions just above the maximum demand for the sake of economy. In connection with this system, duplicate force pumps are used for supplying the several burners of a battery of boilers with heated oil, the circulation of oil from the steam heaters and filters to the burner casings being continuous. As with most oil-burning systems, there is in this connection a special form of furnace front (*vide* figs. 62–64 and 65, Chapter VIII.).

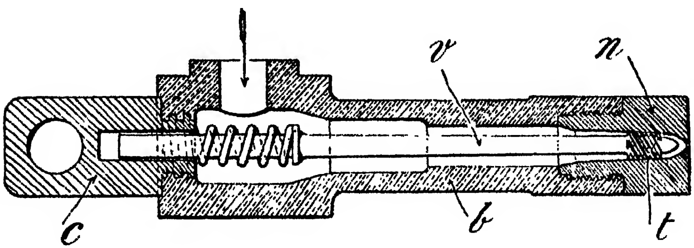


FIG. 40A.—Meyer pressure-jet burner as made by Smith's Dock Co. for natural draught.

In connection with oil-firing on the pressure-jet system, the modified form of "closed end" furnace illustrated by fig. 41 will be seen to contain some points of interest. In this oil-burning furnace—known as the Schutte-Körting, U.S.A.—the construction follows the Howden principle of enclosing the firing end and providing an air regulator which may be used for natural draught, as induced by the difference in temperature of the air in the stokehold from the escaping gases at the funnel top, or is equally well adapted for furnace draught supplied under pressure, the volume of air supplied to the furnace being regulatable by a slide register V in connection with the handle E, to suit varying conditions of firing. The burners used are operated on the pressure system similarly in manner to that adopted in the Meyer burner just described (*vide* fig. 40A), but differs

in that each nozzle is provided with a separate regulating valve B shown in fig. 41, and to there being a removable filter cage F (fig. 42) on each burner for the purpose of arresting any solids that may escape being "held up" by the suction and pressure filter boxes used in connection with the fuel pump. The fuel, as in other pressure-jet oil-burning systems, is heated in two stages to about 260° F., which is, of course, above the boiling point; but, owing to the pressure on the heated oil, evaporation is prevented until it issues in the form of a spray from the burner nozzle. The oil is forced through a comparatively restricted aperture at the apex of the nozzle under a pressure of some 100 lbs. per square inch, with a cyclonic movement derived from the helix V, formed on the burner stem, which is held up to its work at a predetermined distance by the spring B. A cock C is provided on each oil-supply pipe for the purpose of clearing each burner nozzle from accumulated obstruction, the *modus operandi* being to first close the oil cock B, then turn on a blast of steam by opening C; in

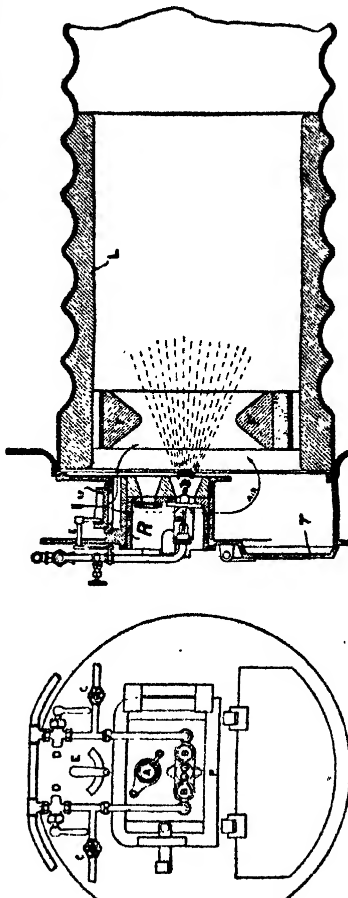


FIG. 41.—Schutte-Körting pressure-jet oil-burning furnace.

addition to which either the diffusing stem or filter cage of each burner can be readily taken out for inspection or cleaning by removing the plugs G and A. To further facilitate which process, the hinged door R carrying the burners can be swung back on the closed chamber T provided for the air intake.

In order to compel the air admitted by the regulator V to press on to the oil jet equally all round, a fire-brick throat or choke ring F (fig. 41) of considerable sectional area is fixed just in front of the furnace front, which it serves as a protection from some of the heat radiated outwards; it at the same time heats the ingoing air, thus

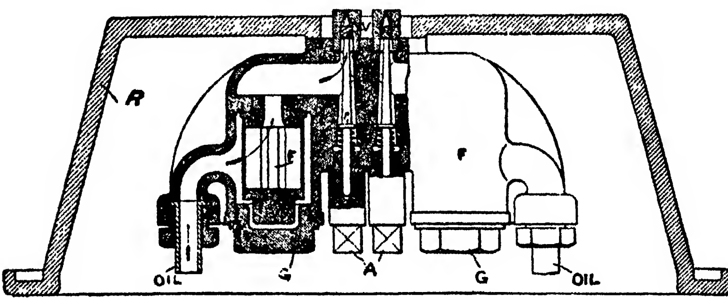


FIG. 42.—Schutte-Körting twin-nozzle pressure-jet burner.

promoting combustion, the intensity of which can be inspected by a sliding observation door A fitted with a mica pane.

One of the greatest advances in the adaptation of the pressure-oil principle has been made by The Wallsend Slipway and Engineering Co., for this firm, after an extensive experience with burners of various types—including both steam and air—have been able to obtain a higher degree of economy, combined with a smokeless combustion, with a burner in which heated oil is supplied at a high pressure, than with either a steam- or air-jet burner.

The Wallsend burner, as will be seen by the illustration (fig. 43), in part resembles that of the original of this type. There is, however, a great difference in the results obtained, but due more to the disposition of the

burner and arrangement of the furnace than to the burner itself. The oil is supplied from an improved form of steam heater of the coil type, and forced into the burner at a steady pressure of from 60 to 80 lbs. per square inch; the complete equipment for efficient working under this oil-burning system is illustrated in figs. 66–69 and 82, Chapters VIII. and IX. The atomising nozzle consists simply of a nipple *n* having a conical-shaped orifice of small diameter,

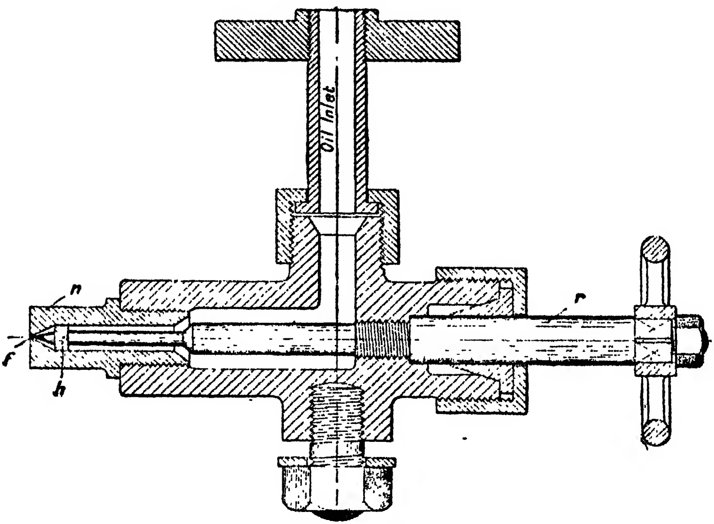


FIG. 43.—Sectional view of Wallsend pressure-jet fuel-oil burner.

from which the spray of heated oil issues in the form of a conoidal column of large diameter, and is capable of burning, in one burner, oil at the rate of from 400 to 500 lbs. per hour. As in most burners having a central pin-valve regulator, the spray column is caused to acquire a rotary movement by means of a helix *h* on the valve stem *r*, the resulting centrifugal effect materially assisting in the widely conoidal diffusion obtained. The illustration (fig. 44) explains the manner of applying burners of this make to a battery of Clarke-Chapman stationary water-tube

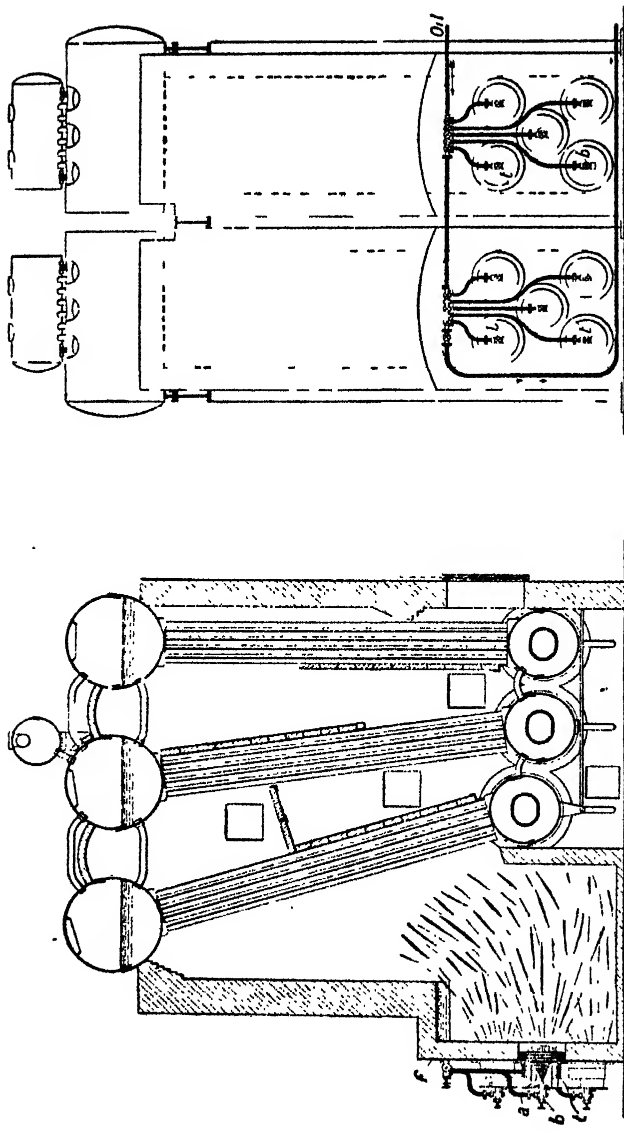


FIG. 44.—Two of a battery of five Clarke-Chapman water-tube boilers (stationary type), with furnaces arranged for firing on the Wallsend oil-burning system.

boilers; the method of applying the Wallsend burner and air intake to the cylindrical furnace of shell boilers arranged for working natural draught, and on the Howden system of forced draught, is fully illustrated by figs. 66–67, Chapter VIII., and as applied to water-tube boilers of the marine type, in figs. 81–82, Chapter IX.

In Kermode's latest type of burner (pressure-jet system), as specially designed for naval and other vessels, either forced or induced draught is recommended. Referring to the illustrations, fig. 45, it will be seen that the oil enters the burner through the channel marked A on the diagrams, and passes between the outer wall of the burner marked D and the inner cylinder marked B, which abuts against the cap nut E.

The end of the cylinder B is an exact and true fit for the outer body D at the end where it abuts against the cap nut E. A series of grooves are cut in the plug end of B parallel to the centre line of the burner, and similar grooves are cut in the face of the plug B at right angles to the axis of the burner. These grooves are shown in the view marked H, and it will be seen that they are tangential to the cone end of the spindle C, which serves to contract or enlarge the opening through the cap nut E. The movement of C is indicated on the graduated wheel marked F.

In this burner the oil fuel is pulverised very completely by being forced through a restricted opening with a rotary motion, which the tangential grooves in the face of the plug end of B imparts to it, and it is distributed in the form of a cone by means of the reaction or deflection which is set up by the oil fuel impinging on the cone end of the spindle C.

The fixed pointer marked G serves to indicate the degree to which the wheel F (which is fixed on the spindle C) has been rotated, either to increase or to diminish the opening through the cap nut E. As in other burners of the pressure-jet type, the oil, after being heated and carefully filtered, is atomised mechanically; the arrangement of the pumps, heaters, filters, etc., used on this system is illustrated by fig. 83, Chapter IX.

In response to the increasing demand for both land and

marine boilers fitted up for oil-firing, several makers other than those mentioned are now supplying oil-burning apparatus of their own make, including the Babcock-Wilcox

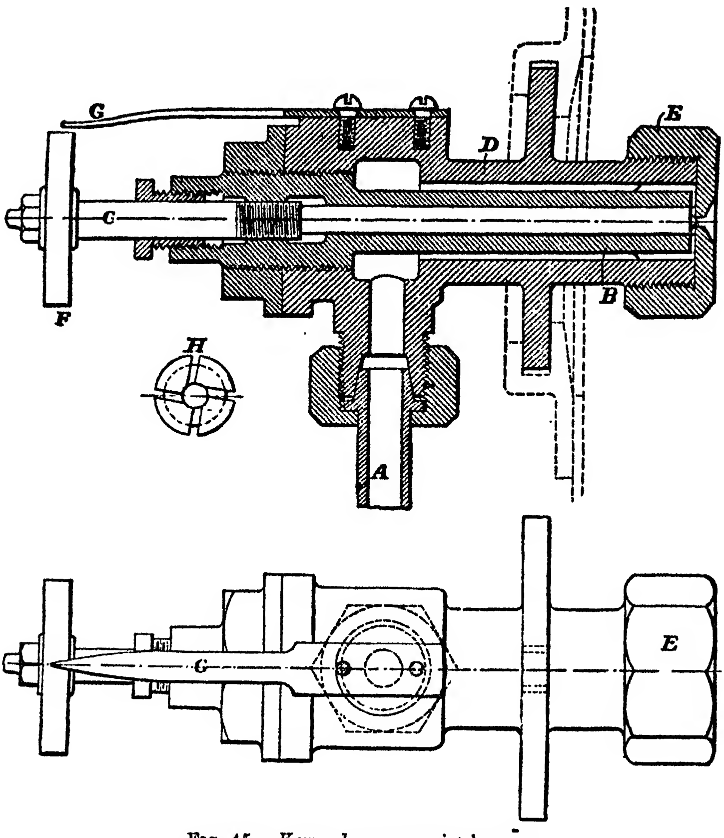


FIG. 45.—Kermode pressure-jet burner.

Co., who have adopted a form of burner working on the pressure-jet system, the arrangement varying somewhat according to type of boiler, but is fairly represented by that shown in fig. 46. A feature in the Moore & Scott Iron Works, U.S.A., pressure-jet burner (*vide* fig.

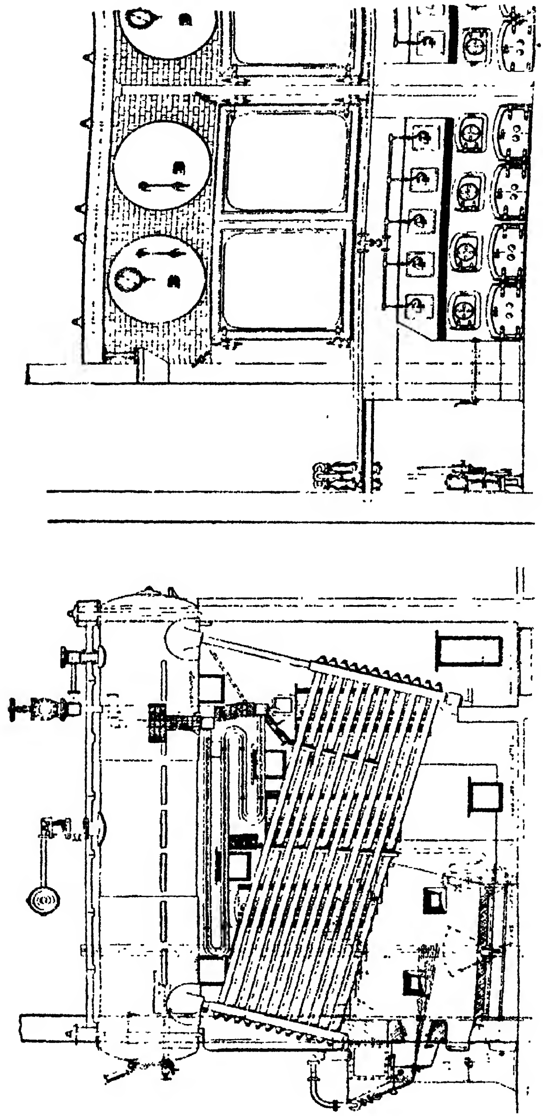


FIG. 46.—Babcock & Wilcox land boiler, fitted with oil-firing on the pressure-jet system as an alternative to coal-firing.

75) is its adaption for a slight variation in the spraying angle while in use. In the Mejani pressure-jet burner (Italy) there are three jets, each supplied from a spiral *oil-way*. The burner made by the Thornycroft Co. (*vide* fig. 47) is also of the pressure-jet type; this burner is fitted on to a special form of furnace front shown in fig. 80, Chapter IX., and is principally supplied for use in naval vessels. It should also be mentioned here that the Yarrow Co. are now fitting their boilers with a pressure-jet type of burner of their own design.

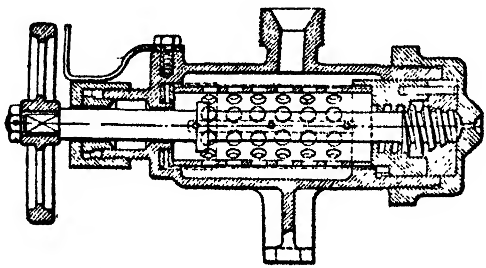


FIG. 47.—Thornycroft pressure-jet burner.

With all pressure-jet burners, however, after prolonged use, whether constructed for spraying heated oil in its liquid state or as a vapour, there is always associated a more or less tendency for the nozzle to choke up; sometimes caused by carbonisation due to the nozzle being in too close contact with the flame, and sometimes from grit and other solids carried over from the filters; and in vapour burners from carbonisation taking place in an overheated vaporiser.

The remedy for this fault in a pressure-jet burner, when using properly filtered and heated fuel oil of any grade—from crude to creosote—it is true, does not impose a very great obstacle to its usefulness, there being generally an attendant on watch (as in the case of an installation of oil-burning apparatus on a battery of boilers) to observe any fluctuation that may take place in the flame intensity of any one of the burners in any particular furnace. In one form

of burner widely used, all that is necessary is simply to slacken back momentarily the feed screw actuating the diffusing cone; in another the remedy consists in temporarily turning off the fuel supply and blowing clear with a steam blast. Nevertheless, if from any cause frequent clearing is required, then the resulting necessity for re-adjustment in the one case, and the change over from oil feed to a steam blast in the other, cannot other than be considered as a contributory cause of some inefficiency.

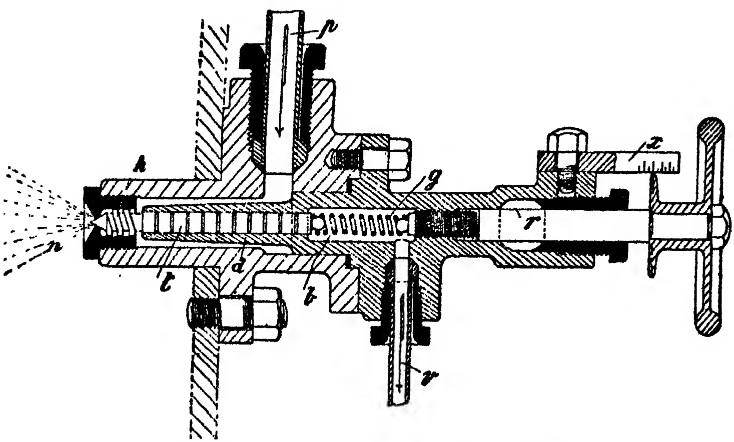


FIG. 48.—Pressure-jet burner, with automatic compensating action.

In the endeavour to eliminate this inherent drawback associated with the burning of oil fuel for steam-generating purposes on the pressure-jet system, the writer has designed the burner illustrated in fig. 48. In the construction and manner of working of this burner there will be noted one essential which differentiates it from all others, viz., in that the diffusing cone n is not held rigidly at a fixed distance from the nozzle aperture, but is held up to its work by a spring g against the pressure feed acting on the area of the stem t. There is the usual helix h close up to the diffusing cone to impart a cyclonic movement to the issuing spray.

The stem t of the diffusing cone is formed to slide freely

within an elongated guide *d*, but is of a sufficiently close fit to prevent oil under pressure at the nozzle end from escaping to the chamber *b* which is not under pressure; however, the rear end of the movable stem *t* is connected by the pipe *v* so as to be placed in communication with either the suction end of the pump or with the supply tank, in order to return any oil that may leak past the movable plunger stem.

As the diffusing cone *n* is held up to the nozzle aperture by the spring *g* against the resistance of the pressure feed, it operates with a floating movement which can be regulated with the utmost nicety by the regulator screw *r* to obtain the desired spraying effect, which, after once being ascertained for any pressure or grade of oil, can afterwards be determined in an exact and convenient manner by the position of the disc pointer along the index dial *x*.

In action any tendency for the accumulation of material that can obstruct the free passages of the liquid through the annular opening permitted by the endways position of the cone *n* behind the nozzle aperture naturally results in an increased pressure in the fuel supply, and hence it follows that the stem *t* is forced back from its normal position to a degree depending on the extent of the obstruction, and by thus momentarily enlarging the area of the jet annulus until the obstruction is cleared away, enables the burner to again adjust itself automatically for the production of a uniform spray so long as fed under constant pressure.

Recognising this advantage of being able to maintain a perfectly clear oil-way in the nozzle aperture of the burner and of preventing any obstruction that may result from displaced accretion in the supply pipe, despite the most careful attention to filtering apparatus provided in duplicate sets, Smith's Dock Co. of North Shields—who have had a very extensive experience with oil-burning on the "Meijer" system—are now supplying burners provided with a supplementary filtering cage. In this it will be noted that the atomiser stem of the burner (*vide* fig. 40A) is held at a fixed distance from the spray orifice, and thus does not lend itself for being freed from obstruction by screwing back the feed regulator, the clearing method hitherto adopted being to blow through with a steam blast from

time to time. This method, however, requires extra piping and stop valves, and for this reason the Schutte-Körting Co. of America, who also make a modified form of Meijer burner (*vide* figs. 42 and 79), have for some time adopted a supplementary filter.

In the improved burners now being supplied by Smith's Dock Co. (*vide* figs. 49, 50, and 50A) the filter cage *m* is entirely self-contained in each burner, and consists of either a perforated ferrule around which, as shown in figs. 49 and 50A, is wrapped a covering of gauze; or, as shown in fig. 50, a thimble is used, having the gauze screen fitted inside. In either construction the filter cage can be quickly removed

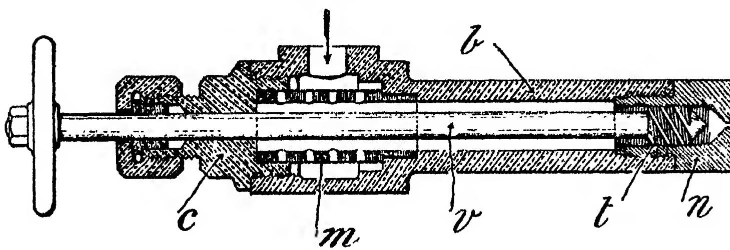
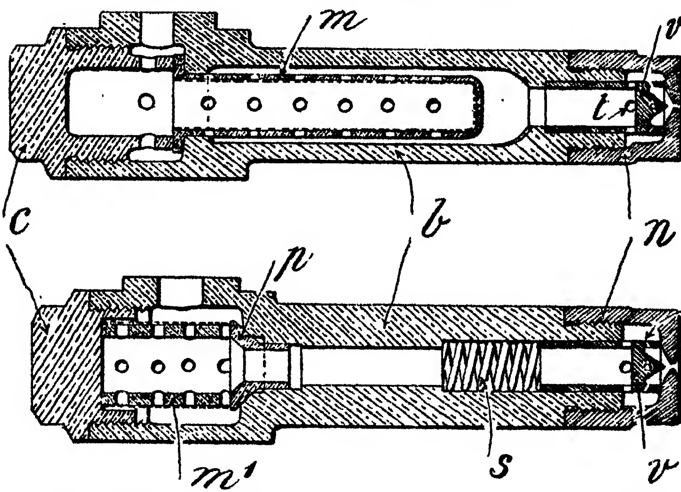


FIG. 49.—Middlemiss pressure-jet burner as made by Smith's Dock Co. for natural draught.

for cleaning by removing the cap *c*. In each of these burners a modified adaptation of the centrifugal principle has been adopted for spraying the oil, that in the Middlemiss burner (fig. 49) consisting of an atomiser regulator *v*, at the nozzle end of which is cut a fine adjustment thread, across which is cut a double lead coarse thread *t* for the oil feed; while in the Thompson burners (figs. 50 and 50A) the atomising cone *v* is held at a fixed distance from the spray orifice, which in each of the three forms of burners is simply a recessed hole from 2 to 3 mm. diameter drilled in the head of a steel nozzle cap *n*; the other parts of the burners, including the barrel *b*, are brass. The atomising cone in the Thompson burners is hollow and divided by a partition; this atomiser is held up—at an oil-tight fit—to the nozzle cap *n*, either by a spring *s* or by differential expansions of different metals as in fig. 50. The oil, after passing through

the filter *m*, first issues from the feed end of the cone, through a series of holes *t*, to the annular space formed between the nozzle cap and the atomiser, whence the oil is forced through a second series of smaller holes t^1 drilled tangentially and in the direction of the deflecting cone; the oil is thus for a given pressure caused to acquire a greater swirl velocity, by reason of the reduced resistance to flow, than can be obtained by a thread channel at the



FIGS. 50 and 50A.—Thompson pressure-jet burners as made by Smith's Dock Co.

end of the atomiser stem as more generally used. Some very satisfactory results have been obtained with these burners in connection with a modified form of furnace front known as the "Meyer-Smith" (*vide* fig. 65, Chapter VIII.).

A very interesting pressure-jet burner of American origin, known as White's (fig. 51), has recently been taken up on the River Tyne by the Brigham Cowan Co. According to this system the burner is surrounded by a perforated air pipe *a*, terminating with a bell mouth *f* to just beyond the burner nozzle. In this, the atomiser cone *n*, which is held up to the nozzle by a stiff spring, has a series of four oil grooves

l cut across the parallel portion of its surface, the grooves being continued in a tangential direction across the coned part of the atomiser to a circular groove just in line with the spray orifice, which, by the way, is of an unusually large diameter. The endeavour in this, as in all pressure-jet burners, is to obtain a maximum swirl effect with a minimum pressure, and indeed a pressure as low as 10 to 15 lbs. can be used, which is an advantage in starting up all cold. More than usual importance is attached to means for thorough heating and accurate regulation of the air supply on this system (*vide* figs. 76–77A), and judging by results obtained with the comparatively turbid Californian and

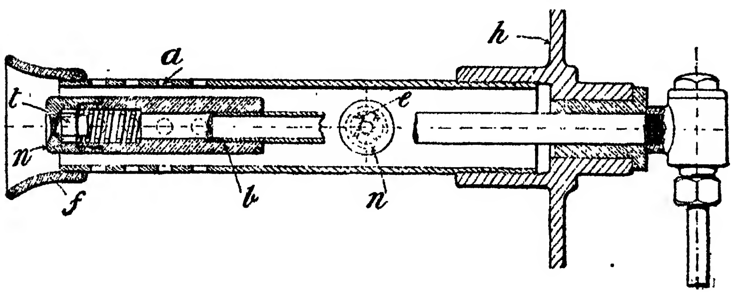


FIG. 51.—White patent pressure-jet burner.[1]

Mexican oils—particulars included in Chapter VIII.—the high temperature and close regulation of the air supply have considerable influence on the economy obtainable with oil-firing on this system.

Vapour Burners.

There is one oil-firing system adapted for burning the heavier grades of liquid fuel in the form of vapour generated from a heated retort, but is little used, although the retort method is commonly adopted for heating stoves, portable furnaces, and for small steam generators of the automobile type; such burners, however (known as blow-flame), are only adapted for the various brands of refined illuminating oils of the paraffin (kerosene) grade, and are fully described in Chapters XI. and XIII.

[1] As used on the *Aquitania*.

According to the Dürr vapour burner system (*vide* fig. 52), the oil is supplied by air pressure through a heated retort, in which it is vaporised, and the vapour is then gasified in a chamber located in the mouth of the furnace. In connection with this system there are two oil tanks for gasifying the oil; the smaller of these is heated by means of a blow-

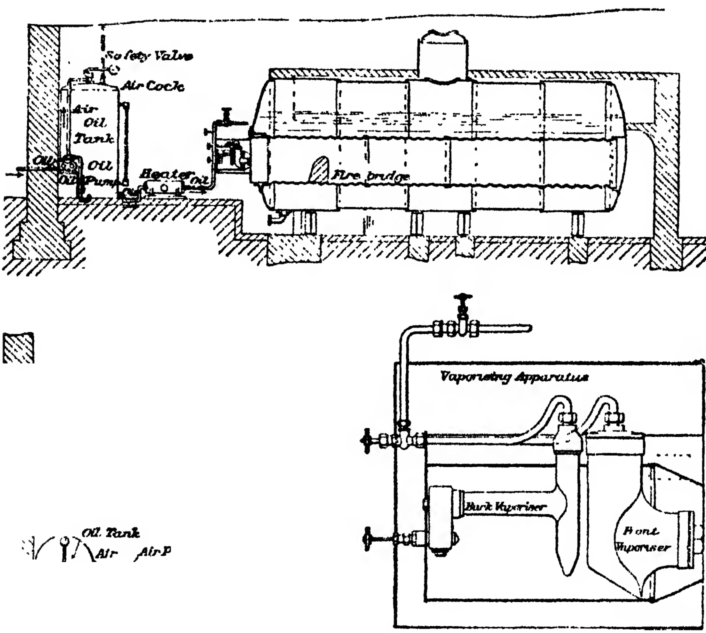


Fig. 52.—Arrangement of Dürr vapour burner.

flame, and as soon as the oil which it contains is sufficiently heated to generate vapour, this vapour is ignited and serves to heat the large gasifier, the vapour from which is burnt in the furnace of the boiler. It is only fair to add that as soon as the flame is thoroughly well established, the temperature inside the outer casing of the larger of the two gasifiers is sufficient to maintain the vaporising process.

There is yet to be described the Prockter system, in which the oil is first heated and then supplied past a float

regulated valve to a chamber containing a drum rotated at a high speed. Air is drawn through perforations in the periphery and caused to mix with oil thown off by centrifugal effect, the mixture thus formed being drawn through a fan and forced direct to the furnace.

In this chapter it has been the endeavour to describe representative types of burners operating under the several systems that have survived the test of actual use. All, excepting two, are essentially spray atomisers, in which the atomising agent is supplied either by:—(1) steam, as in the Urquhart, Holden, Rusden, Orde, Hammel, Peabody, Best, Schurs, and other burners; (2) compresed air, as in the Grundel, Lassoe, Kermode, and others; (3) heated oil under pressure without either steam or compressed air (which type of burner has recently received considerable attention), makes of which are the Swensson, Meyer-Smith, Kermode, Schutte-Körting, Thornycroft, Wallsend, White, and others, these representing the three most successful types of burners, known respectively as (1) steam-jet, (2) air-jet, and (3) pressure-jet; other air-jet and vapour burners not already described are referred to in succeeding chapters.

In this connection, as with developments in other directions, it cannot be said that absolute perfection has been yet attained, though great advance has been made considering the obvious difficulty of devising an apparatus which is capable of dividing into a fine spray a material so thick and viscous as fuel oil. In the successful application of this improved method of firing it is becoming more and more apparent that multiplicity of auxiliary apparatus and extraneous sources of heat should be avoided, and the furnaces made as far as practicable self-contained. Further, it would seem from the number of apparatus in which oil with a varying degree of efficiency can be burnt, that ultimately there will be evolved a greater differentiation in the form of the boiler itself, in order that the fullest advantage may be obtained under the new conditions of firing.

CHAPTER VII.

THE RELATIVE ADVANTAGES OF STEAM, COMPRESSED AIR, AND MECHANICAL ACTION AS AN ATOMISING AGENT FOR LIQUID-FUEL BURNERS.

In the endeavour to ascertain the relative values of compressed air and steam, as atomising agents for the use of liquid fuel for steam-raising purposes, the United States Naval Authorities, as far back as 1902, appointed a board of experts to carry out an exhaustive series of tests, detailed particulars of which are appended at the end of this chapter. The report of this, the "Liquid Fuel Board," extends to considerable length, but concludes with a very interesting commentary and summary of results, as follows:—

1. As the question of supply of fresh water is very important at sea, the use of steam should be obviated as far as possible. On the other hand, air compressors are heavy and take up considerable room. As air compressors, however, are used for many purposes on board ship, it might be possible to have a central plant for all purposes. It is also important to know to what extent it will be necessary to superheat the steam in case it is used as the atomising agent.

2. There is a wide divergence of opinion as to the pressures at which oil, steam, and air should be delivered to the burners. Progressive tests may afford valuable information upon this point.

3. The design of the steam generator. As the experimental boiler now in use by the Liquid Fuel Board (fig. 53) is of the water-tube type, it will be possible to extend the

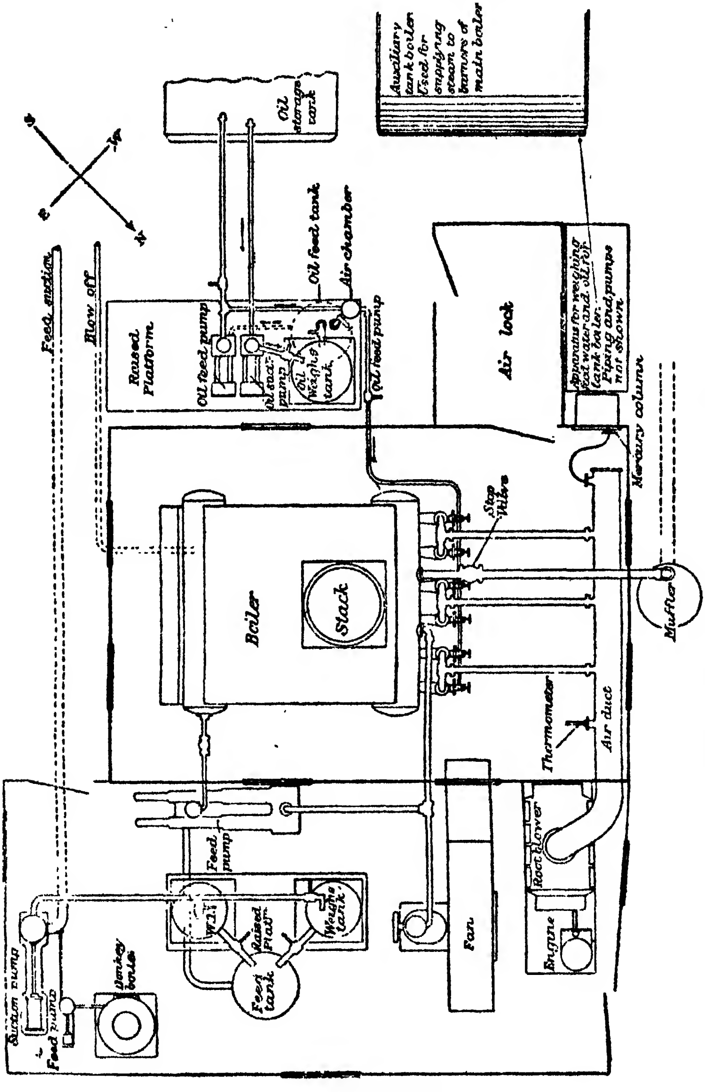


FIG. 53.—Hoheustein experimental boiler plant, used by U.S. Navy Board for liquid-fuel tests.

length of the furnace and make other changes which will give important information as to whether or not it would be advisable to design a special form of marine boiler for oil-fuel installation.

4. The simplest and most economical means of heating the air and the oil. In view of the result of the present experiments and of the information obtained from outside sources, there is no doubt that the air should be heated; and it would seem that, particularly in a water-tube boiler, such heating could be effected in a simple and cheap manner by utilising the heat radiated to the ash-pit.

5. As to the value or necessity of an air receiver when compressed air is used as the atomising medium? Also, can the pulsations of the compressor be reduced or minimised by installing such an intermediate receiver between the compressor and the burner?

6. Experiments could be made concerning the baffling of the gases, for the tests already conducted show that the calorimeter area can be somewhat reduced when using oil.

7. The relative value of leading types of burners. Particularly is it necessary to know whether a simple burner should be installed and provision made for heating the air, or whether an appliance should be installed which partly gasifies the oil before ignition. There are on file in this Bureau over a thousand drawings and specifications pertaining to the use of liquid fuel, and new patents are continually being issued. In view, therefore, of such widespread interest in the subject, the Board deems it important to test representative types of the various classes of burners.

8. The problem as to whether the oil could be consumed under all conditions without producing smoke. In the naval service this is an important question. As there is also a tendency to compel manufacturers to take means to prevent smoke issuing from the stacks of their plants, the question also concerns the general public.

The burner shown in fig. 54 is an air-jet burner of the Oil City Boiler Works, and was used during the seven general tests that were conducted to show, among other things, whether or not it would be possible to secure a greater

evaporative efficiency from the boiler with oil than was secured with coal. Six of these burners, spaced 18 inches

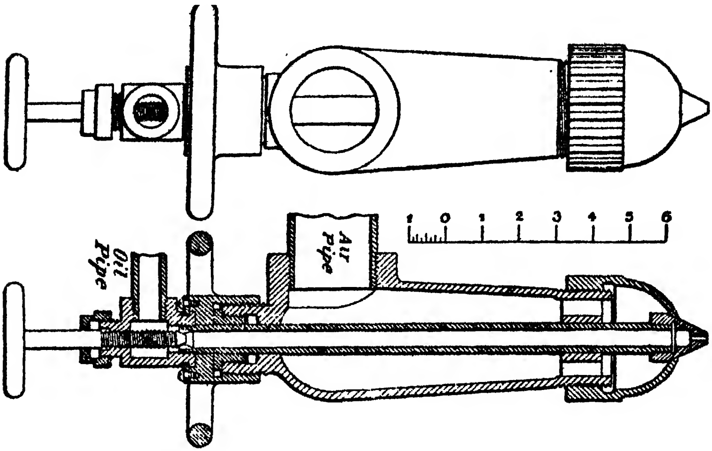


FIG. 54.—Oil City Boiler Works' air-jet burner.

apart, were ranged across the front of the furnace, there being a separate opening in the furnace wall for each

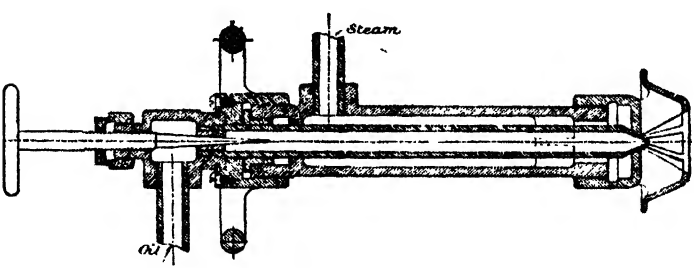


FIG. 55.—Oil City Boiler Works' steam-jet burner.

burner. Considering the burners as arranged in pairs, those of each pair were inclined toward each other at an angle such that their flame impinged near the transverse centre line of the furnace.

Another burner used by the Board was the Hayes. The construction of this burner is shown in fig 56, and the manner of its installation in fig. 56A. Part of the air supply is introduced at the sides of the furnace near the back wall. It then passes through heating pipes AA to the pipe B, the latter extending across the furnace just inside the front wall.

The burners project diametrically through the pipe B, and it is contended that the hot air in this pipe will cause

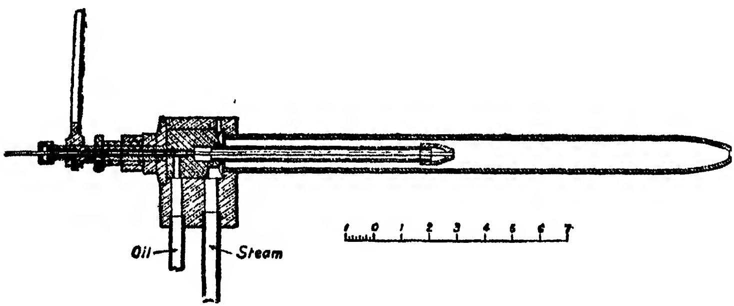


FIG. 56.—The Hayes steam-jet burner.

the oil to be completely gasified before it escapes from the burner orifices. *There is no doubt that the heating of the air is a direct benefit.* Careful and extended experiments will have to be made to show whether this heating could best be effected as in the Howden system of forced draught, or by a simple arrangement of pipes which receive the direct heat of the furnace. The experience of simply heating the pipes during these tests would rather tend to show that this arrangement would not have much endurance. The edges of the holes in the pipe B were found somewhat burned upon completion of the official test. If such impairment could occur after the pipe had been in actual service about twenty hours, it is probable that very little endurance can be expected of such an installation under forced-draught conditions.

On the point of the requisite amount of steam for

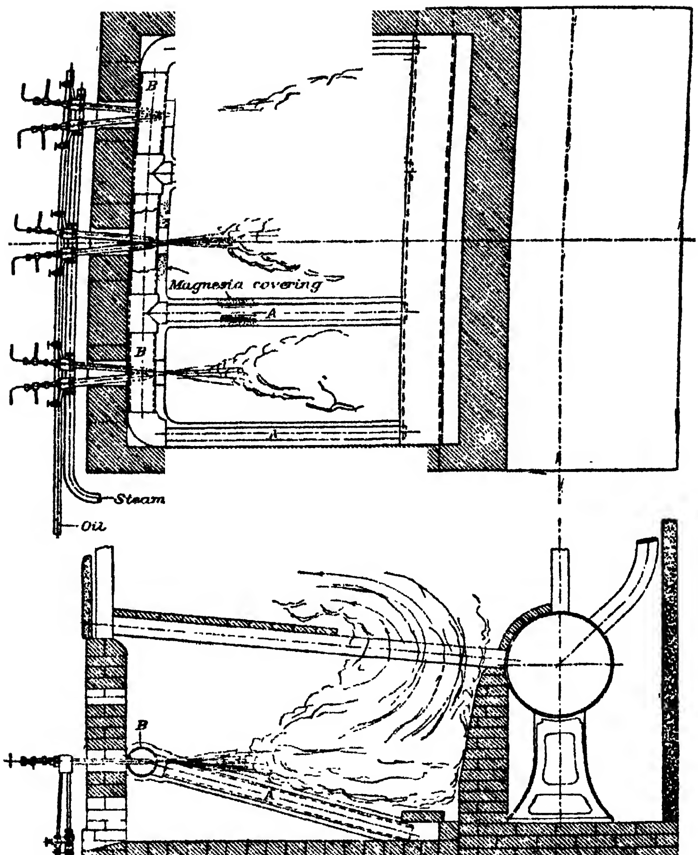


FIG. 56A.—Hayes burners and furnace arrangement.

atomising the oil, the Board made some special experiments. The boiler used was of the cylindrical return-tube type, with two plain cylindrical furnaces. This boiler is piped to furnish steam for the oil burners, and has no other steam pipe leading from it.

The opening from the safety valve was blanked. This boiler is fitted with two oil burners of Oil City Boiler Works' design in each furnace, these burners using air for atomising purposes. After steam was raised one burner in one furnace was found sufficient to keep the steam pressure uniform.

The boiler was put in thorough order at the Navy Yard, New York, and carefully made tight at 100 lbs. pressure. During the oil-burning test great care was taken to keep both the water level and the steam pressures in this boiler uniform. The water used was carefully ascertained in a separate weighing apparatus.

The pressure for atomising purposes, as well as the pressure at which the oil was forced to the burner, was increased each day. It was found that the higher the pressure the greater the amount of water that was evaporated. The efficiency was also slightly greater as higher pressures were used. *The percentage of steam required for atomising the oil, however, also slightly increased as the pressure rose.*

During these tests deflectors were placed in the ash-pan openings, so as to cause the air to be drawn up near the burners, thus effecting combustion near the front of the furnace. The average percentage of steam required for atomising purposes was about 4½ *per cent. of the entire evaporation.*

The Reed combined air and steam burner, fig. 57, was also experimented with, but the results were not satisfactory. The amount of steam consumed in spraying the oil was excessive, being about 1 lb. of steam per pound of oil. The conclusion arrived at was that *the combined use of air and steam in burners is undesirable.*

There is, continues the report, quite a widespread misconception regarding the part that the steam used for atomising purposes plays in effecting combustion. It is supposed by many that after atomising the oil the steam is

decomposed, and that the hydrogen and carbon are again united, thus producing heat and adding to the heat value of the fuel. While it may be true that the presence of steam may change the character and sequence of the chemical reaction, and result in the production of a higher temperature at some part of the flame, such an advantage will be offset by lower temperatures elsewhere between the grate and the base of the stack. *All steam that enters the furnace will, if combustion is complete, pass up the stack as steam, also carrying with it a certain quantity of waste heat.* The amount of this waste heat will depend upon the amount of steam and its temperature at entrance of the furnace. The quantity of available heat, measured in

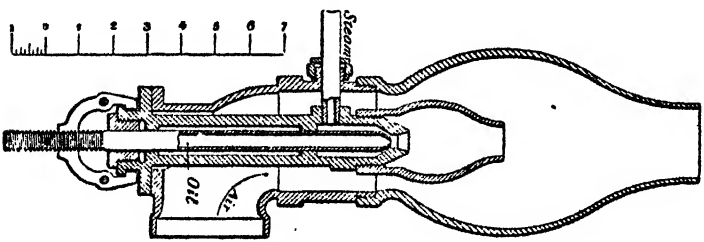


Fig. 57.—Reed combined air- and steam-jet burner.

thermal units, is undoubtedly diminished by the introduction of steam. *In an efficient boiler, it is quantity of heat rather than intensity that is wanted.* For many manufacturing purposes intensity of heat may be of primary importance, but in a marine steam generator a local intense heat is objectionable on other grounds than those of economy, viz., its liability to cause leaky tubes and seams from the unequal expansion of heating surfaces.

It is believed that expert engineers will be able to make important deductions from the trustworthy data that have been so carefully collected. The tables should be carefully studied in connection with the information secured during the coal tests, and the Board enjoins that the two reports be studied together.

The following facts have undoubtedly been proved:—

(*a*) That oil can be burned in a very uniform manner.

(*b*) That the evaporative efficiency of nearly every kind of oil per pound of combustible is approximately the same. While the crude oil may be rich in hydrocarbons, it also contains sulphur, so that, after refining, the distilled oil has probably the same calorific value as the crude product.

(*c*) That a marine steam generator can be forced to even as high a degree with oil as with coal.

(*d*) That up to the present time no ill effects have been shown upon the boiler.

(*e*) That the firemen are disposed to favour oil, and therefore no impediment will be met in this respect.

(*f*) That the air requisite for combustion should be heated if possible before entering the furnace. Such action undoubtedly assists the gasification of the oil product.

(*g*) That the oil should be heated, so that it could be atomised more readily.

(*h*) That when using steam, higher pressures are undoubtedly more advantageous than lower pressures for atomising the oil.

(*i*) That under heavy forced-draught conditions, and particularly when steam is used, the Board has not yet found it possible to prevent smoke from issuing from the stack, although all connected with the tests made special efforts to secure complete combustion. Particularly for naval purposes is it desirable that the smoke nuisance be eradicated, in order that the presence of a warship might not be detected from this cause. As there has been a tendency of late years to force the boilers of industrial plants, the inability to prevent the smoke nuisance under forced-draught conditions may have an important influence upon the increased use of liquid fuel.

(*j*) That the consumption of liquid fuel cannot probably be forced to as great an extent with steam as the atomising agent as when compressed air is used for this purpose. This is probably due to the fact that the air used for atomising purposes, after entering the furnace, supplies oxygen for the combustible, while in the case of steam the rarefied vapour simply displaces air that is needed to complete combustion.

(*k*) That the *efficiency of oil-fuel plants will be greatly dependent upon the general character of the installation of*

auxiliaries and fittings, and therefore the work should only be entrusted to those who have given careful study to the matter, and who have had extended experience in burning the crude product. The form of the burner will play a very small part in increasing the use of crude petroleum. The method and character of the installation will count for much; but where burners are simple in design and are constructed in accordance with scientific principles, there will be very little difference in their efficiency. Consumers should principally see that they do not purchase appliances that have been untried, and have been designed by persons who have had but limited experience in operating oil devices.

The burner used in the first eight series of tests was an air-jet burner (fig. 54), supplied by the Oil City Boiler Works; the burner for the ninth test was a Hayes steam-jet burner, fig. 56; for tests ten to twelve inclusive, an Oil City steam-jet burner was used, fig. 55; and for tests thirteen and fourteen, a combined steam- and air-jet Reed burner was used, fig. 57.

RESULTS OF EXPERIMENTAL TRIALS WITH OIL FUEL BY THE U.S.A. LIQUID FUEL BOARD.

No. of Trial.	Total Pounds Feed Water.	Pounds Steam for Burners.	Moisture (per cent).	Total Pounds Oil Burned.	Pounds Feed per lb. Oil.	Evaporation from and at 212°.	Cub. ft. Air per lb. Oil.
1	117,976	2,820	1·7	10,584	11·15	12·70	34·3
2	96,928	3,770	2·0	9,180	10·56	12·18	37·4
3	78,000	827	1·6	6,122	12·74	14·43	62·8
4	88,604	2,550	1·9	8,602	10·30	11·73	36·7
5	58,529	1,153	1·4	4,668	12·54	14·22	70·0
6	1,192,482	18,240	1·5	96,517	12·36	14·12	55·4
7	104,631	7,800	0·5	9,089	11·52	13·29	78·3
8	92,997	3,950	1·2	9,909	9·39	10·77	36·0
9	43,761	2,524	0·9	3,600	12·16	13·89	...
10	85,791	3,412	0·5	7,360	11·65	13·47	...
11	96,469	4,252	0·6	8,257	11·68	13·45	...
12	105,547	5,305	0·5	8,974	11·77	13·58	...
13	95,605	8,166	0·4	7,692	12·43	14·35	81·4
14	112,115	6,838	0·2	9,216	12·17	14·06	78·0

In the Grundel burner (fig. 58) the oil, heated by a steam coil with live steam, passes through the inside pipe and is diffused radially through a series of small holes. The air, first heated by compression up to 30 lbs., is further heated to a temperature of about 350° F. in the air chamber surrounding the burner, called the air super-heater. Air can also be used at the temperature at which it leaves

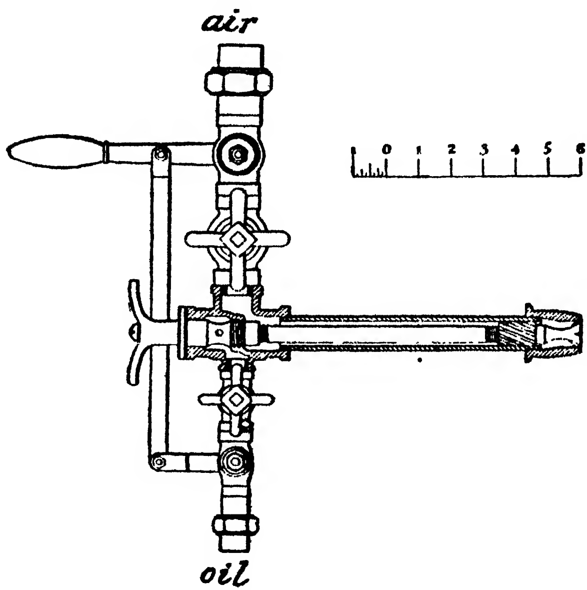


FIG. 58.—Grundel combined air- and pressure-jet burner

the compressor—*i.e.* 260° F. The air supply at about 350° F., and at a pressure of about 30 lbs., surrounds the oil pipe in the burner and passes axially along the pipe until near the end, where it has a whirling motion by being caused to flow through small helical passages arranged like the rifling of a gun. It crosses axially, and whirling through the fine oil streams spurting radially from the end of the burner, breaks up the oil into fine spray. A further air supply (cold) is admitted through the hinged door of

the ash-pan, and is directed up across the path of the flame and heated by a curved fire-brick wall built in the ash-pan close to the front, as shown in fig. 59.

The principal difficulties encountered with this burner were in the regulation of the supply of oil to the heaters by the pump, and the consequent variation of the temperature of the heated oil, and the freedom of flow through the burners. When the oil is heated too high (above 150° F.), some of the volatile gases are given off and mingle with the air pressing on top of the oil in the heater, and thence flow

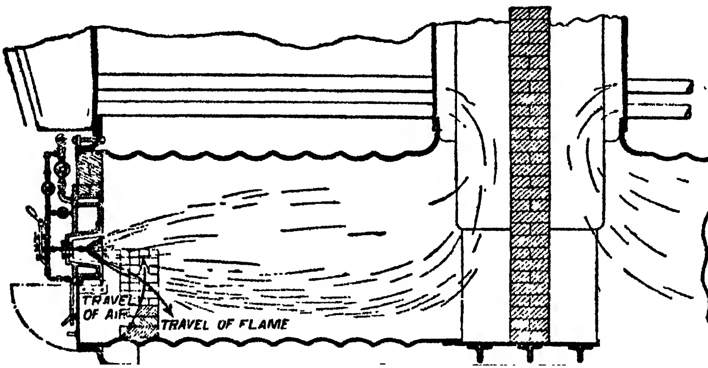


FIG. 59.—Arrangement of oil-fuel furnace with Grundel burner.

with the air into the air superheaters and burners, with the result that a heater may get overheated by pre-ignition from this cause.

It is well for the usefulness of oil fuel in its application to steam raising that, since the foregoing trials were carried out, great improvements have been made in the construction both of burners and furnaces, with the result that the evaporative efficiency of oil has been raised from a maximum of 12–14 lbs. to 15·5–16·5 lbs. of water from and at 212° F. Oil fuel, which has a theoretical calorific value of 19,320 British thermal units per pound, is capable of evaporating 20 lbs. of water from and at 212° F. (theoretically) for every pound of oil consumed, and if the air-jet system is used, from 15·5 to 16·5 lbs. of water can

be evaporated per pound of oil consumed under practical working conditions. That is to say, from 78 per cent. to 83 per cent. of the theoretical value of the oil fuel is recovered for useful work.

One of the best collections of data on the subject of oil-burning is contained in the August 1911 *Proceedings of the A.S.M.E.*, from which the following is an abstract:—In order that liquid fuel of low flash point may be burned with complete combustion, it is necessary that it be either gasified or injected in the form of a spray into the furnace of the boiler; and if into a furnace arranged for coal-firing—*i.e.* one not enclosed by a fire-brick lining by which it becomes highly heated, the oil must be injected in a very finely divided spray composed of very fine particles. If the furnace is short, the oil particles will have a relatively short time for combustion, and consequently will require to be more efficiently atomised. As most of the oils used for fuel are of a heavy and viscous nature, preheating conduces to more perfect combustion in all types of burners, but especially in those in which the oil is atomised without the aid of a compressed air or steam jet. The following are some data as to the amount of *steam* required for atomising fuel oil in boiler furnaces, as obtained from various sources:—

Case 1.—	Steam supplied to burner per lb. of oil	0·537
	Actual evaporation per lb. of oil	13·48
	Percentage	4·0
Case 2.—	Steam supplied to burners per hour	4373·0
	Actual evaporation per hour	96881·0
	Percentage	4·5
	Steam per lb. of oil for atomisation	0·529
Case 3.—	Steam supplied to burners per hour	7087·0
	Actual evaporation per hour	174820·0
	Percentage	4·0
	Steam per lb. of oil for atomisation	0·485
Case 4.—	Steam supplied to burners per hour	5746·0
	Actual evaporation per hour	144079·0
	Percentage	4·0
	Steam per lb. of oil for atomisation	0·475
Case 5.—	Steam used was measured by use of separate boiler.	
	Oil used	34½° Baum.
	Total evaporation per lb. of oil from and at 212°	14·99
	Percentage steam evaporated, used by burner	7·4
Case 6.—	Steam used was measured by calibrated nozzle.	
	Total evaporation per lb. of oil from and at 212°	14·7
	Percentage steam evaporated, used by burner	2·5

Case 7.—Steam used was measured by calibrated nozzle.

Total evaporation per lb. of oil from and at 212°	14·2
Percentage steam evaporated, used by burner	3·6

Case 8.—Steam used was measured by use of separate boiler.

Total evaporation per lb. of oil from and at 212°	15·2
Percentage steam evaporated, used by burner	2·96

Case 9.—Evaporation per lb. of oil (18,700 B.T.U. value) from

boiling point	15·5
Percentage of steam evaporated, used by burner (Hammel)	2·5

From tests made under the direction of the Bureau of Steam Engineering in 1902, the following data are taken: Four tests were made, using steam as the atomising medium. The percentage of total evaporation used by the burners ranged from 3·98 to 5·77 per cent. A number of tests made under Stirling water-tube boilers gave results ranging from 2·1 to 3·42 per cent.

From the above data and general practice and experience, the following statement can be made:—In designing a plant it is entirely safe to assume 4 per cent. of the evaporation of the boilers for steam supply for burners. In operation, if the amount is greater than 3 per cent., it may be concluded that the condition can be bettered.

According to Durand, who estimates with a consumption of 0·4 lb. of steam per pound of oil—which is a fairly representative figure for the amount of steam required—the work equivalent of the steam-jet atomiser process, expended in work done on the oil, should develop from 28,000 to 32,000 foot-lbs. of energy, assuming this amount of steam to be used with a reasonable nozzle efficiency, and under the conditions of, say, 90 lbs. initial pressure absolute and 15 terminal. This figure is impressive. It is probable that, due to wire drawing and inefficiency in the nozzle, the amount of work actually utilised is less than this figure. In any event, however, the price paid for the preparation and introduction of the oil into the furnace is a very heavy one, and the question not unnaturally arises as to whether or not this can be the ultimate method. "*May not some method be developed, mechanical or otherwise, which shall enable us to do the necessary amount of work on the oil without the heavy expenditure involved in the present systems of steam or air atomisation?*"

Data as to the amount of *compressed air* used for atomising fuel oil:—

Case 1.—Cubic feet air supplied per lb. of oil		50
	Pressure, lbs. per square inch	18
	Air, temperature in ° F.	200
	Oil, " "	100
Case 2.—Cubic feet air supplied per lb. of oil		35–50
	Pressure, lbs. per square inch	25–35
Case 3.—Pressure, lbs. per square inch		20
	Air, temperature in ° F.	350
	Oil, " "	150
	Evaporation, lbs. water, from boiling point	15–16
Case 4.—Cubic feet air supplied per lb. of oil		50–70
	Air pressure, lbs. per square inch	1·3–1·6
	Oil " " "	15–16
	Oil temperature, ° F.	200
Case 5.—Cubic feet air per lb. of oil		55–60
	Air pressure, lbs. per square inch	20–25
Case 6.—Pressure of air, lbs. per square inch		5–7
	Temperature of air, ° F.	300
	Cubic feet air per lb. of oil	30–35
	Pressure of oil, head in feet	4–6
	Evaporation from boiling point	15·5–16·5

Data as to *temperature* and *pressure* used for atomising fuel oil *mechanically*:—

Case 1.—Temperature, ° F.		200
	Pressure, lbs. per square inch	120
Case 2.—Temperature, ° F.		260
	Pressure, lbs. per square inch	100–110
	Evaporation, lbs. from 212°	15·8
Case 3.—Temperature, ° F.		155
	Pressure, lbs. per square inch	145
	Evaporation, lbs. from 212°	15·9
Case 4.—Temperature, ° F.		180
	Pressure, lbs. per square inch	170
	Evaporation, lbs. from 212°	16·22

From the foregoing it will be seen that a steam-jet burner requires from 2·5 to 3 per cent. of the total evaporation for atomising the oil under the best conditions; from 3½ to 5 per cent. under average conditions; and from 5½ to 8 per cent. with unskilful adjustments. That compressed-air burners require from 3 to 5 per cent., or even higher, varying according to the efficiency of the compressor plant; so that in point of steam consumption for atomising purposes there is little advantage on either side, excepting when used with a condensing engine. With pressure-jet

burners, less steam is consumed for atomising the oil: that for heating amounting to 0·3 to 0·5 per cent., and for forcing the oil, 0·4 to 0·6 of the total evaporation.

In point of simplicity and cost of oil-burning plant, steam atomisation takes first place; while the difference in cost and space occupied, for an air as against a mechanical atomisation plant, is not very great, the principal advantage of the latter being due to its superior economy and more reliable action; a pressure-jet burner, while being quieter, is also capable of spraying quite 40 per cent. more oil than either a steam- or air-jet burner; and for these reasons has a further advantage, especially when used under forced draught.

Disregarding constructional differences, cost of installation, and general working efficiencies of the three methods of oil-firing:—Pressure-jet apparatus rank first, with average evaporative efficiencies of 79 to 81·5 per cent. of the theoretical maximum; hot-air-jet oil-burning apparatus second, with average efficiencies of 78 to 83 per cent.; and steam-jet burners third, with average efficiencies ranging from 67 to 78 per cent. From which must be debited 0·9 to 1·1 per cent. from the first for pumping and heating the oil; from 3 to 5 per cent. from the second for driving the compressor; and from the third a like amount for atomising purposes.

TESTS MADE BY THE U.S. LIQUID FUEL BOARD.

No. 1.—Test of Oil Fuel in a Hohenstein Water-tube Marine Boiler, June 11, 1902.

[Six hours' duration with forced draught, using air burners.]

Time	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter. Higher Temperature.	Calorimeter. Lower Temperature.	Calorimeter. Quality of Steam.	Height of Water in Gauge Glass.	Temperature. Outside Air.	Temperature. Air in Fire Room.	Temperature. Gases at Base of Stack.	Oil Spraying Air Pressure per square inch.	Draught Air Pressures in Inches of Water. Fire Room.	Draught. Furnace.	Draught. Combustion Chamber.	Draught. Tube Chamber.	Draught. Base of Stack.	Flue Gases. CO_2.	Flue Gases. O.	Flue Gases. CO.	Oil. Burned per hour.	Oil. Total Weight Burned.	Water. Fed per hour.	Water. Total Weight Fed.
	lbs.	° F.	° F.	° F.		ins.	° F.	° F.	° F.	lbs.						%	%	%	lbs.	lbs.	lbs.	lbs.
11 a.m.	275	120	402	302	0·982	2·125	84	117	663	3·20	1·20	0·80	0·60	0·25	−0·45	..	..	..	0	0	0	0
11.30 a.m.	275	112	402	303	·983	2·5	..	116	..	3·14	1·20	·80	·60	·25	− ·50	6·8	8·2	?	..	..	..	..
12 m.	275	122	402	302	·982	2·75	86	119	705	3·17	1·25	·85	·65	·25	− ·45	7·4	8·3	?	1769	1,769	19,406	19,406
12.30 p.m.	275	120	402	304	·984	2	..	120	709	3·23	1·25	·80	·65	·25	− ·50	7·6	9·2	0·4	..	..	..	..
1 p.m.	275	118	402	304	·984	2·13	86	121	717	3·23	1·25	·80	·65	·25	− ·50	7	8·6	1·8	1819	3,588	20,023	39,429
1.30 p.m.	275	120	402	304	·984	2·75	..	122	715	3·11	1·25	·80	·65	·25	− ·50	7·1	9·3	1·4	..	..	..	..
2 p.m.	275	123	402	303	·983	2·25	86	122	712	3·23	1·25	·80	·65	·25	− ·50	..	9	1·3	1776	5,364	19,990	59,419
2.30 p.m.	275	122	402	304	·984	2·5	..	122	711	3·23	1·30	·80	·65	·25	− ·50	..	8	2	..	..	..	..
3 p.m.	275	122	402	303	·983	2·75	86	122	714	3·23	1·30	·75	·65	·25	− ·50	6·8	7·4	2·6	1777	7,141	20,000	79,419
3.30 p.m.	275	123	402	302	·983	2·13	..	122	706	3·23	1·30	·75	·65	·25	− ·50	6·6	8·8	1·3	..	..	..	..
4 p.m.	275	124	402	303	·983	2·13	85	122	690	3·23	1·30	·75	·65	·25	− ·50	6·3	9·8	1·7	1705	8,846	18,823	98,242
4.30 p.m.	275	121	402	303	·983	2·13	..	124	704	3·23	1·30	·75	·65	·25	− ·50	6·3	9	..	..	..	..	..
5 p.m.	275	125	402	304	·984	2·125	85	124	709	3·17	1·30	·75	·65	·25	− ·50	7	9·6	0·8	1738	10,584	19,784	117,976
Average	275	120·7	..	..	·9834	..	85·4	121	704·6	3·20	1·27	·78	·642	·25	− ·488	6·97	8·77	1·5	1764	..	19,663	..

State of weather, bright sun, clear sky. Barometer at noon, 30·02 inches. Kind of fuel, Beaumont oil.
Revolutions of fan blower, 327 per minute. Revolutions of Root blower, 126 per minute. Draught openings into furnace, 666 square inches.

9.10 a.m. Two middle burners lighted. Root blower driven by steam from small independent boiler.

10.5 a.m. Steam pressure in main boiler, 100 pounds. All auxiliary machinery begun to be driven by steam from main boiler. All six burners alight. Smoke very uniform and much thinner than corresponds to chart No. 1.

5 p.m. The floor of the furnace is badly warped from the heat. The floor consists of one layer of fire-brick on wrought-iron floor plates on wooden sleepers with dirt rammed between the sleepers. The floor of furnace, back wall of same, and first two baffles are red hot. There are two disk-like accumulations of red-hot carbon on the back wall. The middle and larger one is about 15 inches in diameter.

Next day: The disk of carbon has been removed and examined. Structurally, the carbon is indistinguishable from coke. The shape is that of a crater, 5 inches thick around the edges and 2 inches thick in the centre. The larger crater was opposite the middle burners. A smaller one was opposite the left-hand burners and there was practically none opposite the right-hand burners. Evidently a very slight difference of conditions will cause or prevent their formation.

No. 2.—Test of Oil Fuel in a Hohenstein Water-tube Marine Boiler, June 26, 1902.

[Eight hours' duration with natural draught, using air burners.]

Time.	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter. Higher Temperature.	Calorimeter. Lower Temperature.	Calorimeter. Quality of Steam.	Height of Water in Gauge Glass.	Temperature. Outside Air.	Temperature. Air in Fire Room.	Temperature. Gases at Base of Stack.	Temperature. Air from Root Blower.	Air from Root Blower, Pressure per sq. in.	Draught Pressures in Inches of Water. Furnace.	Draught Pressures in Inches of Water. Combustion Chamber.	Draught Pressures in Inches of Water. Tube Chamber.	Draught Pressures in Inches of Water. Base of Stack.	Flue Gases. CO_2.	Flue Gases. O.	Flue Gases. CO.	Oil. Burned per hour.	Oil. Total Weight Burned.	Water. Fed per hour.	Water. Total Weight Fed.
	lbs.	° F.	° F.	° F.		ins.	° F.	° F.	° F.	° F.	lbs.					%	%	%	lbs.	lbs.	lbs.	lbs.
9 a.m.	275	122	404	305	0·983	2·5	72	94	520	90	0·73	−0·15	−0·15	−0·25	−0·35	6·5	11·5	0·2	0	0	0	0
9.30 a.m.	275	130	404	306	·984	2·5	..	100	525	92	·73	− ·15	− ·15	− ·25	− ·40	6·4	11	·6	..	..	..	..
10 a.m.	275	122	404	308	·985	2·5	74	99	525	95	·67	− ·15	− ·15	− ·25	− ·35	6·6	10	1·3	786	786	9,503	9,503
10.30 a.m.	275	130	404	308	·985	2·5	..	102	508	97	·79	− ·15	− ·15	− ·25	− ·35	6·6	10·2	·9	..	..	..	..
11 a.m.	275	140	404	307	·984	2·5	76	103	500	99	·73	− ·15	− ·20	− ·25	− ·35	7·1	9·6	·6	748	1534	9,061	18,564
11.30 a.m.	275	130	404	307	·985	2·25	..	103	495	100	·85	− ·15	− ·20	− ·25	− ·40	7·8	9·6	·5	..	..	..	..
12 m.	275	138	404	306	·984	2	78	105	495	102	·85	− ·15	− ·20	− ·25	− ·35	7	10·3	·6	759	2293	9,537	28,101
12.30 p.m.	275	129	404	306	·984	2·25	..	104	497	102	·79	− ·15	− ·20	− ·25	− ·35	7·2	9·3	·9	..	..	..	..
1 p.m.	275	129	404	307	·984	2·25	80	106	497	103	·79	− ·15	− ·20	− ·25	− ·35	7·5	9·5	0	751	3044	9,895	37,996
1.30 p.m.	275	130	404	307	·984	2	..	109	495	104	·79	− ·15	− ·20	− ·25	− ·35	7·8	9·7	0	..	..	..	..
2 p.m.	275	122	404	306	·984	2·5	82	110	497	106	·79	− ·15	− ·20	− ·25	− ·35	7·4	10·6	·3	765	3809	10,066	48,062
2.30 p.m.	275	136	404	307	·984	2·13	..	111	497	106	·79	− ·15	− ·20	− ·25	− ·35	7	11·4	0	..	..	..	..
3 p.m.	275	132	404	306	·984	2	82	111	500	108	·79	− ·15	− ·20	− ·25	− ·35	7·8	10·2	·1	769	4578	9,482	57,544
3.30 p.m.	275	130	404	307	·985	2·13	..	112	502	108	·79	− ·15	− ·20	− ·25	− ·35	7·5	10·5	·2	..	..	..	..
4 p.m.	275	124	404	307	·985	2·25	82	111	500	109	·79	− ·15	− ·20	− ·25	− ·35	7·8	9·9	·2	773	5351	10.373	67,917
4.30 p.m.	275	130	404	306	·984	2·25	..	112	505	110	·79	− ·15	− ·20	− ·25	− ·35	7·8	9·9	·4	..	..	..	..
5 p.m.	275	122	404	307	·984	2·5	82	114	505	111	·79	− ·15	− ·20	− ·25	− ·35	7·8	9·9	·4	771	6122	10,083	78,000

State of weather, bright sun, no clouds. Barometer at noon, 29·70 inches. Kind of fuel, Beaumont oil.
Revolutions of Root blower, 100 per minute. Draught openings into furnace, 124 square inches.

A Brown quick-reading pyrometer placed on the floor of the furnace with the platinum fully exposed to the direct radiations from the flames, registers 1600° F. under the middle burners. At a point about 18 inches in front of the burner tip and 6 inches below its centre line the temperature is 1950° F. The corresponding temperatures for the side burners are about 100° lower. The flames reach for the most part to the middle of the combustion chamber. Only rarely do flames penetrate the tube chamber.

5.10 p.m. The smoke was very uniform throughout the test, and so slight as to be barely visible. There are three irregular patches of carbon deposit, one on each side wall of the furnace and one on the back wall. The largest one, on the right side, is dome-shaped, and fully 4 inches thick in the centre.

No. 3.—Test of Oil Fuel in a Hohenstein Water-tube Marine Boiler, August 4 to 9, 1902.

[Endurance test of 116 hours' duration with natural draught, using air burners.]

Date.	Watch.	Maximum and Minimum Values observed during each Watch. Steam Pressure by Gauge.	Temperature of Feed Water.	Quality of Steam.	Height of Water in Gauge Glass	Temperature. Outside Air.	Temperature. Air in Fire Room.	Temperature. Gases at Base of Stack.	Temperature. Air from Root Blower.	Root Blower. Revolutions per Minute.	Root Blower. Air Pressure per Sq. In.	Maximum and Minimum Values observed during each Watch. Draught Pressure in Inches of Water. Furnace.	Combustion Chamber.	Tube Chamber.	Above Tubes, below Drums.	Base of Stack.	Oil. Burned per hour.	Oil. Total Weight Burned.	Water Fed per hour	Water Total Weight Fed.	Flue Gases. Time Sample was Drawn.	CO_2.	O.	CO.	Height of Barometer at Mid-Watch.	State of Weather.
		lbs.	° F.		ins.	° F.	° F.	° F.	° F.		lbs.						lbs.	lbs.	lbs.	lbs.	P.M.	%	%	%	ins.	
Mon., Aug. 4	Noon to 4 p.m.	275	127	0·986	3·50	93	121	558	122	93	1·34	−0·25	−0·20	−0·30	−0·40	−0·40	818	3,270	9,942	..	1.45	7·4	10·8	0·1	29·99	Clear.
	4 p.m. to midnight	275	119	·987	4	88	124	575	126	99	1·40	−·20	−·20	−·30	−·40	−·45	864	..	10,580	..	..	..	..	..	29·82	
Tues., Aug. 5	Midnight to 8 a.m.	275	122	·986	3	80	112	575	112	98	1·34	−·20	−·25	−·33	−·40	−·50	826	10,102	10,133	205,471	A.M.	..	..	..	30·03	Clear.
	8 a.m. to 4 p.m.	275	122	·986	3·25	88	120	590	122	104	1·34	−·18	−·25	−·30	−·38	−·48	847	..	10,520	289,627	8.45	7·5	10·3	·1	30·00	Cloudy; thunder-storm.
	4 p.m. to midnight	275	120	·987	2·75	88	120	590	122	100	1·34	−·18	−·25	−·28	−·35	−·46	847	..	10,518	..	..	..	..	..	29·76	
Wed., Aug. 6	Midnight to 8 a.m.	275	122	·987	3	82	116	610	118	104	1·40	−·20	−·28	−·30	−·40	−·50	872	..	10,657	459,028	..	..	..	..	29·87	Rain.
	8 a.m. to 4 p.m.	275	120	·987	5	95	125	610	122	104	1·34	−·18	−·28	−·35	−·40	−·50	848	..	10,437	542,523	9.30	7·8	10·1	0	29·86	Thunder storm.
	4 p.m. to midnight	275	130	·987	3·50	73	112	605	118	104	1·40	−·20	−·23	−·35	−·45	−·50	838	..	10,256	624,567	..	..	..	..	29·69	
Thur., Aug. 7	Midnight to 8 a.m.	270	124	·987	3	74	110	598	114	100	1·40	−·20	−·25	−·35	−·45	−·50	837	..	10,251	706,574	..	..	..	..	29·89	
	8 a.m. to 4 p.m.	276	128	·987	4	90	116	600	114	100	1·40	−·15	−·23	−·30	−·40	−·48	..	64,174	10,414	789,889	10.30	7·9	10·8	·3	29·98	Clear and cool.
	4 p.m. to midnight	275	124	·985	4	81	118	595	116	100	1·40	−·20	−·25	−·33	−·40	−·48	820	70,733	10,140	..	..	..	..	..	29·77	
Fri., Aug. 8	Midnight to 8 a.m.	275	124	·985	3·75	74	106	595	108	103	1·40	−·20	−·25	−·35	−·45	−·50	819	77,284	10,151	952,212	..	..	..	..	29·89	Clear; then partly cloudy.
	8 a.m. to 4 p.m.	274	128	·985	3·75	88	119	625	124	95	1·40	−·20	−·25	−·33	−·40	−·50	816	83,813	10,127	1,033,225	9.30	7·8	9·7	0	29·91	
	4 p.m. to midnight	274	125	·983	2·50	87	121	605	129	102	1·40	..	−·22	−·31	−·40	−·48	..	90,265	10,145	1,114,388	..	..	..	..	29·81	
Sat. Aug. 9	Midnight to 8 a.m.	275	128	·982	3	80	118	590	116	95	1·40	−·18	−·22	−·30	−·40	−·43	782	96,517	9,762	1,192,482	..	..	..	..	30·05	Partly cloudy.

Kind of fuel, Beaumont oil. Draught openings into furnace, 348 square inches.

No. 4.—Test of Oil Fuel in a Hohenstein Water-tube Marine Boiler, September 12, 1902.

[Six hours' duration with natural draught, using "Hayes" steam burners.]

Time.	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter.			Height of Water in Gauge Glass.	Temperature.				Pressure of Steam used in Spraying Oil.	Draught Pressures in Inches of Water.				Flue Gases.			Oil Burned.		Steam used by Burners.		Feed Water.	
			Higher Temperature.	Lower Temperature.	Quality of Steam.		Outside Air.	Air in Fire Room.	Oil in Weighing Tank.	Gases at Base of Stack.		Furnace.	Combustion Chamber.	Tube Chamber.	Base of Stack.	CO_2.	O.	CO.	Per hour.	Total.	Per hour.	Total.	Per hour.	Total.
	lbs.	° F.	° F.	° F.		ins.	° F.	° F.	° F.	° F.	lbs.					%	%	%	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1.30 p.m.	275	122	388	302	0·988	2·5	76	96		460	30	−0·20	−0·20	−0·20	−0·32	5·6	12·7	0·2	0	0	0	0	0	0
2 p.m.	275	119	386	306	·991	2·75	77	98	72·5	440	32	− ·18	− ·20	− ·20	− ·35	4·8	13·7	·3	..	..	..	..	..	..
2.30 p.m.	274	134	386	308	·992	2·5	78	98	..	..	32	− ·20	− ·20	− ·20	− ·32	..	..	..	572	572	456	456	6702	6,702
3 p.m.	275	130	386	308	·992	2·75	79	100	72	..	33	− ·21	− ·20	− ·20	− ·38	..	..	..	..	..	..	..	..	..
3.30 p.m.	275	140	386	308	·992	2·5	78	98	..	..	32	− ·20	− ·20	− ·20	− ·38	..	..	..	601	1173	402	858	7311	14,013
4 p.m.	275	137	386	303	·989	2·75	77	99	72	..	30	− ·20	− ·20	− ·20	− ·35	..	..	..	..	..	..	..	..	..
4.30 p.m.	275	136	386	303	·989	2·5	78	100	..	450	32	− ·20	− ·20	− ·20	− ·38	..	..	..	602	1775	553	1311	7241	21,254
5 p.m.	275	118	384	306	·991	2·5	74	100	72	445	32	− ·20	− ·20	− ·20	− ·38	..	..	..	..	..	..	..	..	..
5.30 p.m.	275	120	386	308	·992	2·5	74	99	..	..	32	− ·21	− ·21	− ·21	− ·40	..	..	..	590	2365	459	1770	7480	28,734
6 p.m.	275	130	386	306	·991	2·5	73	99	72	..	32	− ·22	− ·21	− ·21	− ·40	..	..	..	..	..	..	..	..	..
6.30 p.m.	275	120	384	306	·991	2·5	70	97	..	..	32	− ·22	− ·21	− ·21	− ·40	..	..	..	639	3004	295	2065	7691	36,425
7 p.m.	275	122	384	306	·391	2·5	70	94	71	..	32	− ·22	− ·21	− ·21	− ·41	..	..	..	..	..	..	..	..	..
7.30 p.m.	275	120	386	306	·991	2·5	68	92	..	..	32	− 22	− ·21	− ·21	− ·41	..	..	..	596	3600	459	2524	7336	43,761

State of weather, partly cloudy.
Draught opening into furnace, 180 square inches.
Barometer at noon, 30·16 inches.
Pressure in oil-pipe air chamber, 20·3 lbs.
Kind of fuel, Beaumont oil.
Temperature over fire-room platform, average 165° F., maximum 170° F.

10.30 a.m. Started fires. The boilers were under steam yesterday and the water is already quite warm.

12.30 to 1.30 p.m. Data taken during this period shows about the same evaporative capacity as during the succeeding six hours. The smoke ranged from ½ to 1. Average, ¾, by Ringelmann charts. A few ounces of carbon was deposited near the right-hand burner orifice. The burners made comparatively little noise, probably not more than a quarter as much as the compressed-air burners used in the preceding eight tests; but on the other hand, the flames were longer, reaching well into the tube chamber.

No. 5.—Test of Oil Fuel in a Hohenstein Water-tube Marine Boiler, September 19, 1902.

[Eight hours' duration with natural draught, using steam burners.]

Time.	Steam Pressure by Gauge.	Temperature of Feed Water.	Calorimeter.			Height of Water in Gauge Glass.	Temperature.				Pressure of Steam used in Spraying Oil.	Draught Pressures in Inches of Water.				Flue Gases.			Oil Burned.		Steam used by Burners.		Feed Water.	
			Higher Temperature.	Lower Temperature.	Quality of Steam.		Outside Air.	Air in Fire Room.	Oil in Weighing Tank.	Gases at Base of Stack.		Furnace.	Combustion Chamber.	Tube Chamber.	Base of Stack.	CO_2.	O.	CO.	Per hour.	Total.	Per hour.	Total.	Per hour.	Total.
	lbs.	° F.	° F.	° F.		ins.	° F.	° F.	° F.	° F.	lbs.					%	%	%	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
10.30 a.m.	275	118	380	308	0·994	2·75	62	90	..	600	28	−0·20	−0·15	−0·20	−0·60	7	10·6	0	0	0	0	0	0	0
11 a.m.	275	118	380	308	·994	2·75	64	90	68	..	30	−·20	−·20	−·20	−·60	..	..	..	..	..	..	..	..	..
11.30 a.m	275	115	380	308	·994	2·50	66	91	..	..	30	−·20	−·20	−·30	−·60	7·1	11·1	0	983	983	475	475	11,181	11,181
12 m.	275	116	380	310	·995	2·50	67	99	68	605	30	−·20	−·20	−·30	−·60	..	..	..	..	..	..	..	..	..
12.30 p.m.	275	118	382	310	·995	2·50	68	100	..	..	31	−·20	−·20	−·30	−·60	7	11·2	·1	968	1951	365	840	11,148	22,324
1 p.m.	275	112	380	310	·995	2·50	69	100	68	..	30	−·20	−·20	−·30	−·60	..	..	..	..	..	..	..	..	..
1.30 p.m.	275	120	380	310	·995	2·50	71	100	..	605	30	−·20	−·20	−·30	−·60	7	11·1	0	934	2885	423	1263	11,222	33,546
2 p.m.	275	120	384	310	·994	3	71	98	68	..	30	−·20	−·20	−·30	−·60	..	..	..	..	..	..	..	..	..
2.30 p.m.	270	118	384	310	·994	2·50	70	96	..	580	30	−·20	−·20	−·30	−·60	6·6	11·2	0	915	3800	326	1589	10,551	44,097
3 p.m.	275	120	384	310	·994	2·50	70	94	68	..	28	−·20	−·20	−·30	−·60	..	..	..	..	..	..	..	..	..
3.30 p.m.	275	120	384	310	·994	2·50	71	100	..	575	28	−·20	−·20	−·30	−·60	6·6	11·8	0	851	4651	399	1988	10,287	54,384
4 p.m.	275	122	384	310	·994	3	70	94	68	..	28	−·20	−·20	−·30	−·60	..	..	..	..	..	..	..	..	..
4.30 p.m.	274	118	384	310	·994	2·50	70	102	..	595	30	−·20	−·20	−·30	−·55	7·4	10·8	0	826	5477	479	2467	9,733	64,117
5 p.m.	275	118	380	310	·995	2·50	70	106	68	..	32	−·22	−·22	−·25	−·60	..	..	..	..	..	..	..	..	..
5.30 p.m.	274	120	380	310	·995	2·50	70	104	..	610	32	−·22	−·22	−·25	−·60	7·2	10·6	0	970	6447	452	2919	11,071	75,188
6 p.m.	274	120	380	310	·995	2·50	70	100	69	..	32	−·21	−·20	−·25	−·58	..	..	..	..	..	..	..	..	..
6.30 p.m.	275	120	360	308	1·001	2·75	70	99	..	..	29	−·20	−·20	−·28	−·58	..	..	..	913	7360	493	3412	10,608	85,791

State of weather, thin clouds. Barometer at noon, 30·20 inches. Kind of fuel, Beaumont oil.

Draught opening into furnace, 500 square inches. Pressure in oil-pipe air chamber, 20 lbs.

Temperature over fire-room platform, average 177° F., maximum 184° F. Temperature of superheated steam for burners, 444·4° F.

The angular setting of the side burners is changed so as to direct their flames more toward the centre of the furnace. Heretofore the side walls of the furnace have absorbed an undue amount of heat, as shown by their glow after extinguishing the burners.

Curved sheet-iron deflectors have been placed in what were formerly the ash-pit openings, so as to direct the entering air upward at an angle against the flames.

The smoke averages about ½, the maximum being ½, by Ringelmann charts.

A disk of carbon 9 inches in diameter was deposited on the back wall opposite the centre burners.

CHAPTER VIII.

OIL FUEL FOR MARINE PURPOSES.

DURING the last few years the application of oil fuel for marine purposes has received very considerable attention from all the leading countries of the world and now, on many of the more important lines, promises to supersede coal entirely. The original source of this application is no doubt the extensive use which oil fuel finds on the steamers of the Caspian Sea, and which began as far back as 1870, the burner employed being of the steam-jet type, and introduced by Spakovsky, who was the first to use steam as a pulverising agent. Later on, however, the Caspian Sea fleet was fitted with the Lenz burner (*vide* fig. 7). This was no doubt the starting-point of the fitting out with liquid-fuel burners of those vessels which have since been fitted for oil-burning apparatus, including, in addition to the Shell Line Co.'s fleet, the Netherland, the China Mutual, the East Asiatic Companies; as well as many of the Anglo-American Oil Co., the Eagle Oil Transport Co., the Anglo-Saxon Petroleum Co., and soon after this many vessels belonging to several other lines specialising in oil-carrying and general cargo steamers were fitted with oil-burning apparatus, though none of these use it on so extensive a scale as the first-named company. The application of oil fuel to the marine services offers greater difficulties than its use in stationary engines and locomotives, and consequently the experiments made in different parts of the world have been more varied, more especially as the conditions governing its use in the two branches of the

service, the mercantile and the naval, differ so considerably. The chief advantages, however, are common to both, and, as has already been pointed out, include the great reduction of stokehold staff, ease and regularity of working, cleanliness, rapidity of loading up the supply of fuel, saving in space occupied by fuel, and augmented accommodation for cargo, passengers, or crew. Also with regard to the speed attained by a ship consuming liquid fuel in comparison with a coal-burning boat, it has been found that an appreciably better speed can be maintained by the oil-fired steamer. This is mainly attributable to the cleaning of fires being dispensed with, and that full steam pressure can be constantly maintained with oil fuel, the boilers being fired automatically; whereas in coal-fired ships considerable difficulty is often experienced in keeping up a full head of steam, with a temperature in the stokehold often rising as high as 100° to 110°, or even 115° to 125° in the tropics. This is not due to a deterioration of boilers or machinery, or to the quality of the coal, but to a difficulty in getting the trimming and stoking done to the fullest capacity of the boilers. Such an obstacle would not be present in the case of liquid fuel being used.

It was soon realised in the first attempts to use liquid fuel that it is not only the burner on which good and economical working is dependent, but also upon the arrangement of the furnace itself (*vide* fig. 60). The difference between burning coal and using oil is that with the former it is possible to get a very extended heating effect, while the tendency with oil is to concentrate the heat too much. To overcome this difficulty, certain dispositions of fire-brick in the furnace are made. The special method adopted on the *Cowrie*, one of the first vessels of the Shell line to be fitted up for oil-burning, was as follows:—The column and bridge of fire-brick, which are usually placed above the centre of the grate, and under the arch, so as to break up the flame as it comes from the burner, was found to have one serious defect, in that, although it splits up part of the flame, it allows a considerable portion to fly over the bridge in one unbroken mass. To remedy this, the column of fire-brick supporting the bridge was extended to about the same height above, so

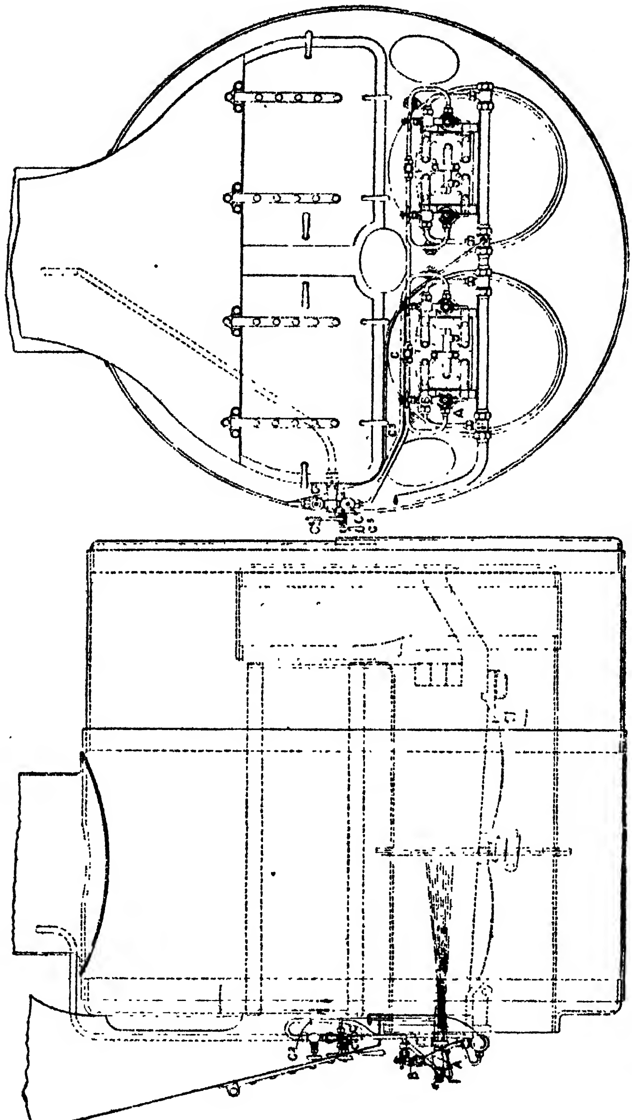


FIG. 60.—Arrangement of double-furnace marine boiler fitted for mixed oil- or coal-firing, and with set of four Holden steam-jet burners.

that the flame was split up, thereby diffusing the flame more equably.

From the experiences gained in this boat, one of the difficulties was the trouble of getting up steam from all cold, due to the tendency to steam too fast, as it is not easy to keep a small flame going, and the heat increases too suddenly. To obviate this the burner was ignited intermittently; that is to say, if you light up at 7 o'clock, shut off at 7.30, at 8 o'clock light up again, shut off at 8.30, and continue this until the vessel is ready to start.

Another point in connection with this method of oil-firing by steam-jet burners, was that for a higher economy something remained to be done in regard to the burner, in order to save the 4 or 5 tons of oil per day found necessary to provide the steam for pulverising the oil.

An interesting comparison may here be made of the difference in consumption on this boat when burning oil, and on a previous trip while burning coal. From Port Said the time occupied while burning liquid fuel was only 14¾ days, whereas while burning coal the time occupied between Port Said and London was 16 days. The daily consumption of liquid fuel may be put at about 26 tons as compared with a consumption of from 30 to 32 tons of good Welsh coal.

Other interesting pioneer results in connection with the mercantile service are provided by the record of experiments made on the Roumanian mail steamer *King Charles I.* towards the end of 1901.

This ship plied between Constantza and Constantinople, and could carry 60 first, 60 second, 300 third class passengers, and 400 tons of merchandise.

Length of steamer	350	feet.
Gross tonnage	2360	tons.
Net tonnage	839	,,
Bunker capacity	400	,,
Maximum speed	19	knots.
Total h.p. of engines (two vertical tripl expansion with surface condensers)	6500	i.h.p.
Revolutions per minute . . .	150	

Heating surface of boilers (four boilers of marine type, of which two are ordinary boilers with four furnaces and two double ones with eight furnaces each) .	5800 feet.
Pressure of boilers	$12\frac{1}{2}$ atmos

For the purpose of using the new fuel the vessel was fitted with all the necessary accessories. As a measure of prudence, during the experimental period of one and a half months oil fuel was only used under one boiler, the other continuing to burn coal. The oil was stored in the water-ballast tanks, the supply which the vessel could take in these tanks being 280 tons. A duplex pump served for raising the oil from these tanks into two elevated reservoirs installed above the boilers. From these reservoirs the oil flowed by gravitation to the injectors or pulverisers. In the tanks, as well as in the elevated reservoirs, the oil was heated by a steam coil.

After the experiments with the one boiler were completed, all the boilers in the vessel were adapted for burning liquid fuel, since when nothing but petroleum residuals was burned. The internal arrangement of the furnaces was also modified after a while; in these at the beginning the air required for combustion entered only from underneath the injector, and this was subsequently arranged for the air to enter the furnace partly from below the injector and partly through holes in the bottom, which separates the furnace from the chamber in the rear, air entering through these holes having the effect not only of completing the combustion, but also of beating back the flame, and in this manner while abating the speed of the flame, also modified its intensity.

The writer of this record points out the following danger from carelessness of the crew in regard to closing the air valves when the furnace is not in use. When the fires are put out on the vessel arriving in port, if the valves for the admission of air into the furnaces are not closed hermetically, the cold air penetrates in large quantities into the furnace, and unequal contractions in the interior of the furnaces are caused, this producing leakages in the boiler flues. It is therefore necessary on the one hand that the stokers should always take care when

extinguishing the fires to close well the air admission valves in the furnaces.

When coal was burned on this steamer there were three shifts of six stokers, or eighteen stokers in all; but with liquid fuel only six stokers were required, and even these had but light work.

With coal the consumption of fuel on the vessel was about 150 tons of Westphalian coal per voyage—that is, from Constantza to Constantinople and back, plus the consumption while in port; the consumption of oil fuel for the same trip being reduced to between 70 and 80 tons.

With the object of overcoming the difficulties consonant with the use of steam for pulverising purposes, the Meijer system of injecting the oil into the furnaces under pressure by a common steam or donkey pump was tried on a Dutch line of steamers, in which the exhaust steam of the pump is returned to the main condenser, thus avoiding the loss of fresh water.

According to this system the oil on its way from the tanks to the donkey pump, and from there to the nozzles in the furnace fronts, is heated and filtered by the arrangement shown in fig. 61.

In this, A is a valve box with suction pipes from the oil tanks and connections to pump the residuals from one tank to the other.

B is a heating apparatus which heats the residue slightly by the exhaust steam of the donkey pump on its way to the condenser, thus rendering it more fluid.

C is a filter for cleaning the residuals of dirt; C^1 is a reserve filter to be used while the filter C is cleaned; D is a donkey pump; D^1 is a reserve donkey pump, to be used in case of repairs to pump D; E is a heating apparatus to heat the residuals to 200° F. with the live steam on its way from the boiler to the donkey pump D; F is a pressure gauge, showing the pressure on the residuals; G is a thermometer, showing the temperature of the residuals before they enter the furnace; H is a spring-loaded escape valve, regulating the pressure on the oil.

To bring the residue to its proper temperature, before injecting into the furnaces, the hollow plug cocks J and N

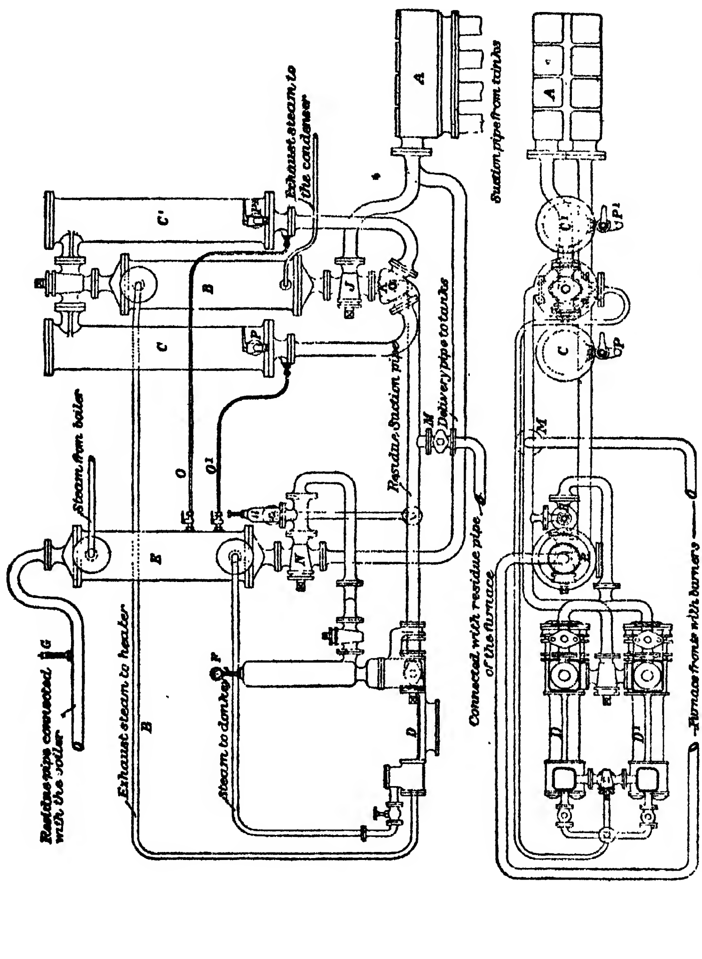


FIG. 61.—Arrangement of heating, filtering, and pumping apparatus used on the Meijer oil-firing system

are opened upwards, and the three-way hollow plug cock K opened to one of the pipes coming from the filters. The cock M is also opened, all stop valves on the injectors shut, and the donkey pump D or D^1 started.

This now draws the fuel from the valve box A, through the cock J, heater B, filter C or C^1, and hollow plug cock K, and forces the residue through cock N to heater E, and from there through the delivery pipe, which is now in connection with the suction pipe through the cock M, thus circulating the fuel through the heaters and filter.

As soon as the thermometer G shows the required temperature, about 200° F., the cock M is closed, and the stop valves on the injectors opened, the heated fuel now spraying into the furnaces, where it is ignited by a common torch. The small steam pipes O and O^1 serve to blow steam through the wire gauze inside the filters for cleaning purposes, the dirt being discharged through the drain cocks P and P^1.

In constructing the heating apparatus B and F great care must be taken to make the joints between oil and steam spaces in such a manner that no possibility exists for the residuals to leak into the latter, which might occur in the event of the residuals being under higher pressure than the surrounding steam.

In such case the oil would go with the steam into the condenser, and from there into the boilers, and have an injurious effect. It is better to have as few joints as possible between these two spaces.

With the above method of injection, however, another medium has to replace the steam used in the jet to break up the fuel into small particles when entering the furnace, and for this reason, instead of the common orifice, a Körting injector is used, which, on account of the threaded diffuser inserted in this apparatus and of the pressure on the residuals, gives the latter a great centrifugal velocity, which causes a more perfect breaking up of the residuals as soon as they leave the injector.

In arranging an ordinary furnace of a marine boiler for the burning of liquid fuel, the inventor emphasises the following points:—

First. — With a single Körting injector no more than a quantity of oil sufficient for about 80 i.h.p. per hour can be injected into the furnace (enlarging this injector would infringe upon its good working), and this often renders it necessary to place two and sometimes three injectors (*vide* figs. 40–42 and 62–64) on each furnace to allow of the injection of the maximum quantity of fuel necessary for the generation of the steam wanted, and ample room should thus be provided on the furnace front as well as in the furnace itself to allow for these injectors.

Second. — The air necessary for combustion, about 200 cubic feet per pound of residuals, has to be well heated before coming into contact with the particles of fuel, and this contact should be as complete as possible, to allow every particle

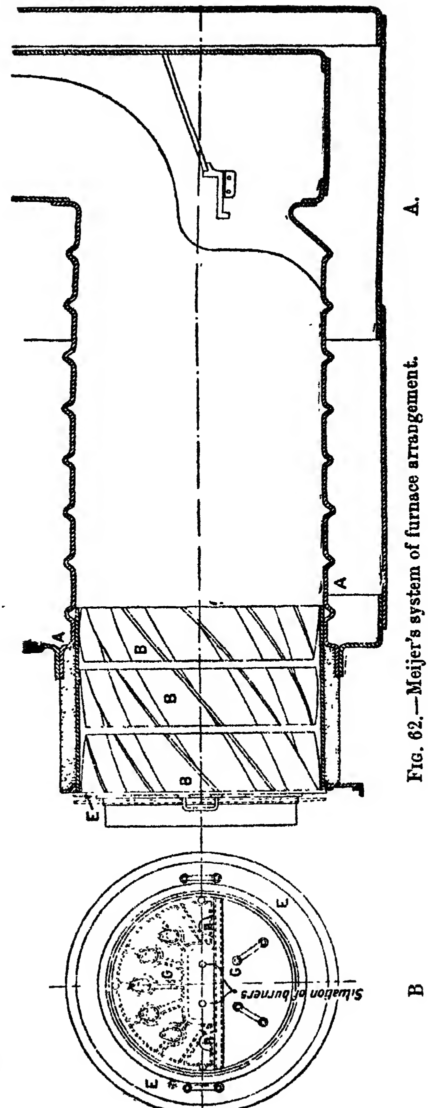


FIG. 62.—Meijer's system of furnace arrangement.

to be well surrounded by the hot air flowing in. Care should be taken to let the fresh air from without obtain free access to the furnaces, and therefore the stoke-hold gratings on deck should be made large and in accordance with the quantity of air necessary for combustion.

Third.—To ensure proper contact between the air and the fuel, the air flowing in should surround the injected residuals on all sides in the furnace.

Fourth.—The jet of oil should spray freely into the furnace and burn there without touching any of the boiler plates or brickwork, as this would cause the formation of solid carbon.

Fifth.—A good quantity of brickwork is necessary in the furnace, not only to act as a bridge to prevent the gases from escaping unburnt through the funnel, or as a protection for the back of the combustion chamber, but also to allow the brickwork, after being heated, to work as a heat accumulator, which is necessary to keep the furnace at a high temperature.

Sixth.—The opening of the fire-bridge for the outflow of gases should be adjusted very accurately, as an opening too small or too large would produce a dense smoke. Experience with Borneo oil showed 0·6 square foot of opening per burner to be about the required size.

Taking the above points into consideration, the inventor designed a furnace as shown on the annexed drawings (figs. 62–64).

To the front end (figs. 62–62A) of the furnace A is fitted an annular ring B, provided with a series of spiral ailettes C, secured edgewise upon and around its external surface so as to traverse it longitudinally. The spaces between these ailettes form channels to conduct the air, which is thus heated by radiation from the flame inside the ring. So that the air before entering the furnace shall be thoroughly heated, the ailettes traverse the perimeter spirally. This ring is made in two or more short lengths, so as to facilitate its manufacture, the different lengths being kept somewhat apart, thus forming the circular openings, through which part of the air enters and ignites the fuel inside the apparatus. The rest of the air comes

into contact with the fuel on emerging from the end of the channels D (fig. 62A). The annular space formed by these channels, by which the air enters at the stokehold side, is provided with a suitable damper E properly guided and rendered adjustable, so that the amount can be suitably regulated.

The furnace front is closed at the stokehold side by covers G, G, which are made in two pieces, one carrying the injectors, and the other serving as an inspection door for inside.

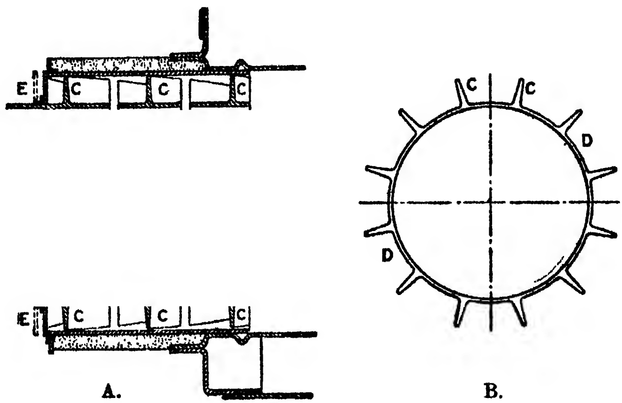


FIG. 62A.—The Meijer system of furnace arrangement.

According to the Meijer system, otherwise known as Meyer's, as modified by the Smith's Dock Coy., each nest or group of burners, *b*, *b*, fig. 63, is controlled by an ordinary stop valve *r*, the spraying cone being set at a fixed distance from the nozzle aperture, and not used to regulate the rate of feed. The oil is supplied at constant pressure along a pipe *p* in excess of the average rate of feed to the furnace, the surplus being forced past a relief valve *v* and returned along pipe *m* to the suction filter, so that the stokehold regulation can be carried out without reference to the speed of the pumps, although for the sake of economy these are naturally regulated under running conditions just above the maximum demand

of the furnaces. The furnace front of the boiler is fitted with rings *g*, on the outer side of which are cast a series of angularly disposed ribs *d*, for the purpose of heating the ingoing air through the annular spaces *a*, and of also intercepting direct radiation from the furnace outwards.

The description of this oil-firing system would be incomplete without some reference to the recently introduced

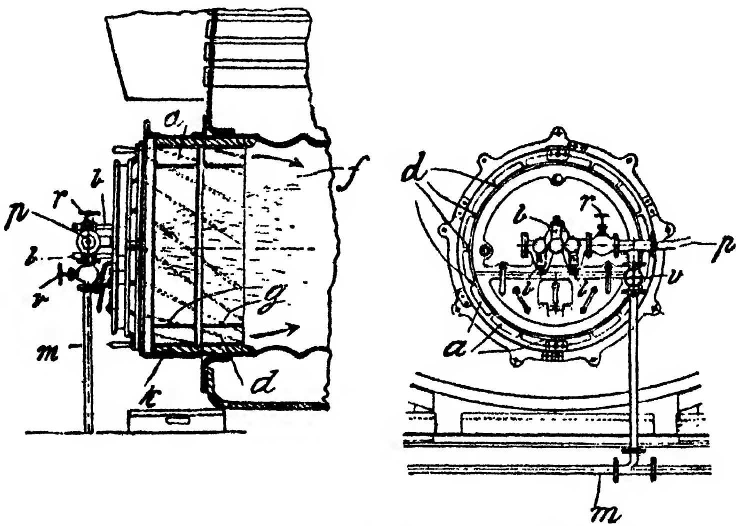


FIG. 63.—Arrangement of Meijer furnace with triple-jet pressure burner

Meyer-Smith furnace front, as in this, sheet steel entirely takes the place of cast iron; the front is consequently lighter to handle, which is a consideration in fitting up, in converting from oil- to coal-firing, or *vice versâ*. Referring to the elevation and plan views, fig. 65, the furnace front in its improved form consists of: (1) a circular sliding damper A for controlling the air supply through passages C; (2) a circular sliding damper B for controlling the air supply through the outer passages D; (3) passages C having spiral vanes for heating and imparting a rotary

movement to the entering air; (4) outer air passages D; (5) a steel cone E to serve as a direction plate; (6) a flat steel extension plate F to fit the furnace mouth; (7) a

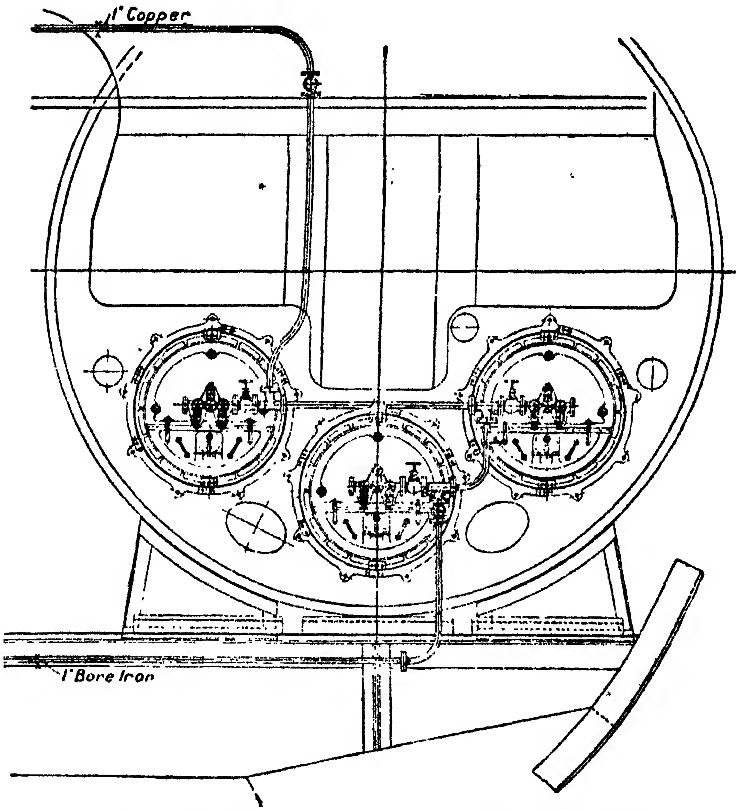
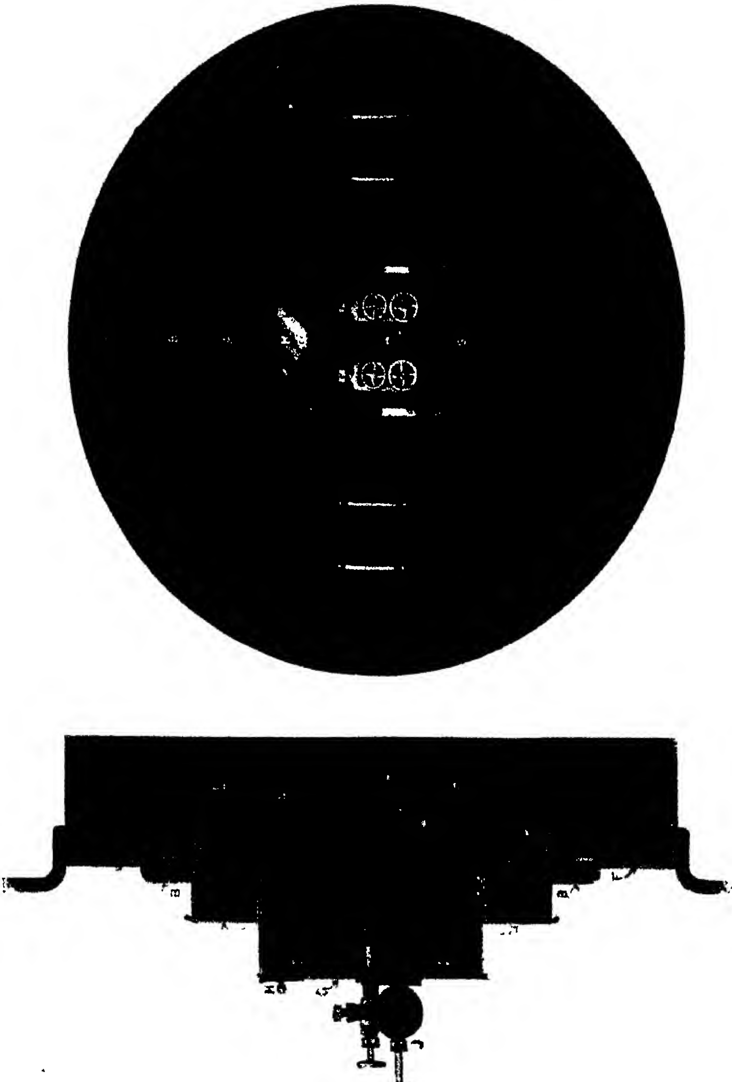


FIG. 64.—Arrangement of furnace fronts on marine boiler fitted with Meijer pressure-jet burners.

front plate G to which the burner boxes are fitted; (8) an observation and lighting door H; and finally (9), a pair of pressure-jet burners J, which may be either as described in fig. 40A, or as in figs. 49 to 50A, Chapter VI. The



following are details of a test recently carried out on this system at the works of the Smith's Dock Coy., North Shields:—

Dimensions of boiler, 8 feet 9 inches by 8 feet 6 inches, with two plain furnaces, 31 inches external diameter, 6 feet 1 inch long; total heating surface, 470 square feet.

Temperature of atmosphere	54° F.
Temperature of air supplied to the flame	870° F.
Temperature of furnace (maximum)	2375° F.
Temperature of combustion chamber	1280° F.
Temperature of smoke-box	580° F.
Temperature of feed-water	120° F.
Temperature of oil in heaters	210° F.
Pressure of oil to burners	35 lbs.
Pressure of steam in boilers	80 lbs.
Consumption of oil per hour	164·35 lbs.
Water evaporated per hour	2592 lbs.
Water evaporated from and at 212° F. per lb. of oil used	15·7 lbs.
Evaporative efficiency per cent.	90·2
Brand of oil used, 2 parts Texas with 1 part Borneo.	
Specific gravity (mixed)	·944
Flash point (close test)	246° F.
Moisture in oil used	4 per cent.
Sulphur in oil used	0·32 per cent.
Evaporation per lb. of oil, corrected for incombustibles, in lbs. of water from and at 212° F.	17·4 lbs.

Under the Schutte-Körting system (*vide* figs. 41–42), instead of using a ring formed with spirally arranged deflecting ribs, a choke ring of fire-brick is placed just forward of the furnace front for the purpose of causing the ingoing air to converge on to the fuel cone. The furnace is also lined with fire-brick for some distance in from the front, on which is hinged a door carrying a pair of burners of similar construction to that shown at *b, n, t, r*, excepting that each burner is separately controlled and provided with a filter box for intercepting any solid matter carried in with the fuel supply.

For oil-firing at sea there appears to be a strong case in favour of the pressure-jet or mechanical system, this not requiring an air compressor, and consequently less liable to go wrong, besides being much quieter in action and consuming only one-third the steam used by a compressor, and less than one-fourth that consumed in a steam-jet burner for an equal evaporative duty.

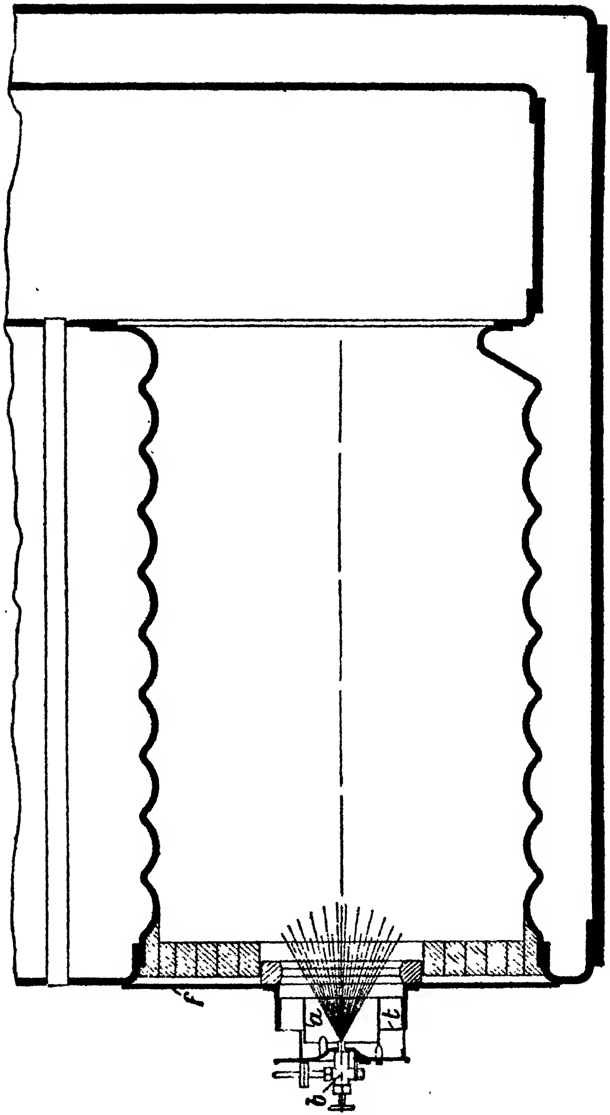


FIG. 66.—Section of marine type boiler furnace fitted with Wallsend oil-burning apparatus to suit natural draught.

In the application of oil-firing to boilers of stationary and marine types on the Wallsend pressure-jet system,

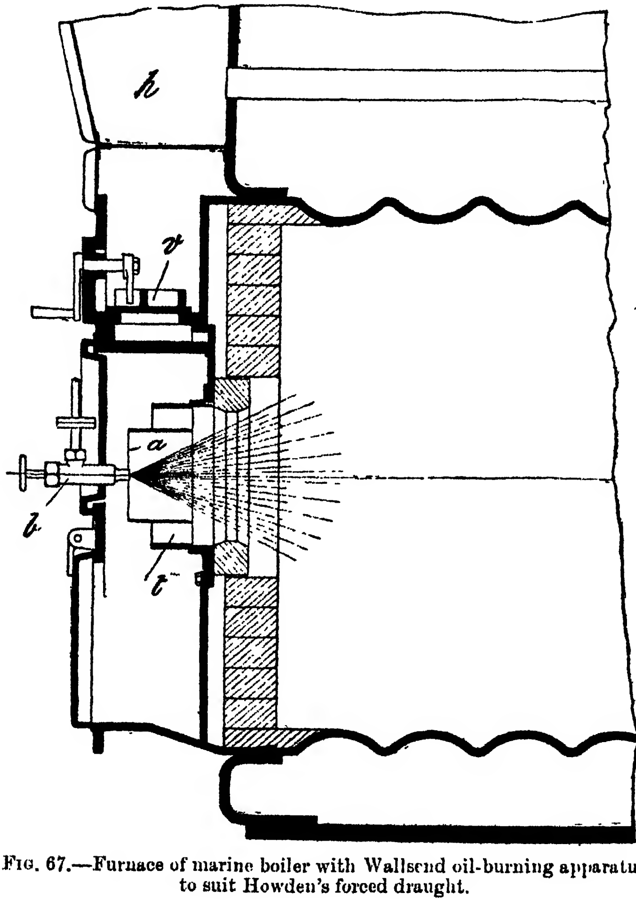


FIG. 67.—Furnace of marine boiler with Wallsend oil-burning apparatus to suit Howden's forced draught.

there are no fire-bars fitted in the furnace, the whole circumference being thus available for heating surface. The Wallsend system differs again in the use of a single burner *b* of great capacity (*vide* fig. 43), and also in the

form of the furnace front, which may be arranged for natural draught and for forced draught (*vide* figs. 66–67). The oil, after being first filtered and heated, is forced into the centre of the furnace in a widely diffused spray from a single burner, the spray bursting into flame at a distance of 6 to 8 inches from the nozzle. As there is no brick lining used, the boiler naturally heats up sooner than would be the case when burning coal; and, moreover, the lower portion of the furnace walls is heated uniformly with the upper portion, one result of which is an improved circulation of the water in the boiler; also, needless to add, there is practically none of that straining action which results from unequal expansion and contraction due to rapid changes of temperature consequent on the opening of the door as in coal-stoking.

In the construction of the Wallsend furnace, the front constitutes the principal feature; in this (*vide* fig. 66) there is a concentric air trunk having lateral openings at its outer end. This air trunk projects concentrically within a second air trunk *a*, carried by the furnace front *f*, and the annular space *t* between the inner and outer air trunks is fitted with deflectors arranged to cause the ingoing air to have a spiral motion. One advantage of this construction is obvious, as by its means direct radiation outwards through the furnace front is prevented.

In using forced draught on Howden's system (*vide* fig. 67) with closed furnace front, an efficiency as high as 16·25 lbs. of water evaporated from and at 212° F. has been obtained per pound of oil burnt, the oil proving to have a calorific value of 18,770 B.T.U., thus demonstrating a boiler efficiency as high as 84 per cent.

The report below adduces sufficient evidence of the great improvements that have been made in applying oil fuel for steam-raising purposes:—Size of boiler (marine return tube type) 11 feet diameter by 11 feet 6 inches long, with two furnaces 3 feet 3 inches inside diameter, and fitted up to work on the Howden system of forced draught. Total heating surface, 1358 square feet. During the trials the burners worked well, the flame

filling the furnace so that the combustion space was effectively utilised. There was no visible smoke during a considerable part of the tests, and at no time was there more than a slightly perceptible discharge.

SUMMARY OF RESULTS OF TRIALS OF THE WALLSEND PATENT LIQUID FUEL BURNING SYSTEM WORKING WITH HOWDEN'S FORCED DRAUGHT.

Date of trial	8/9/10	8/9/10
Duration of trial . . . . hours	3½	2
No. of burners per furnace . . No.	1	1
Size of burner	18	16
Class of oil used . . . . . (Scotch)	Pumpherston	Pumpherston
Calorific value (net) of the oil . . B.T.U.	18,770	18,770
Specific value of the oil at 60° F.	0·868	0·868
Steam pressure . . . . lbs. per sq. in.	155	155
Average temperature of feed water . degrees F.	115	120
Pressure on oil at burners . . lbs. per sq. in.	145	170
Temperature of oil at burners . . degrees F.	155	180
Pressure of air entering furnaces . ins. of water	2¼	⅞
Temperature of air entering furnaces . degrees F.	190	185
Description of smoke at chimney top . . .	Very light to none	Very light to none
Temperature of gases at foot of chimney degrees F.	488	420
Weight of oil burned per hour . . . lbs.	932	633
Weight of oil burned per hour per burner . ,,	466	316·5
Weight of water evaporated per hour . . ,,	13,050	9,000
Total moisture in steam (by surface condensing calorimeter) . . . . . . per cent.	1	none
Weight of water evaporated per lb. of oil burnt lbs.	14·00	14·22
Equivalent evaporation from and at 212° F. . lbs.	15·91	16·22
Equivalent evaporation from and at 212° F. per sq. ft. of heating surface per hour . . lbs.	10·92	7·55
Thermal efficiency of boiler . . . . per cent.	82·3	83·9

(Signed) ARCHIBALD BARR.

The manner of fitting up a pair of marine boilers under this system may be gathered from the illustrations, figs. 68 and 69, which include a hand pump A, temporary heater B, and oil tank C for use in starting up when all cold; the Wallsend oil-firing system is also shown applied to water-tube and locomotive boilers in Chapters IX. and X. The plant used after a head of steam has been raised consists of a pair of oil force pumps E, suction filter D, pressure equalising vessel F, oil-fuel steam heater J, oil

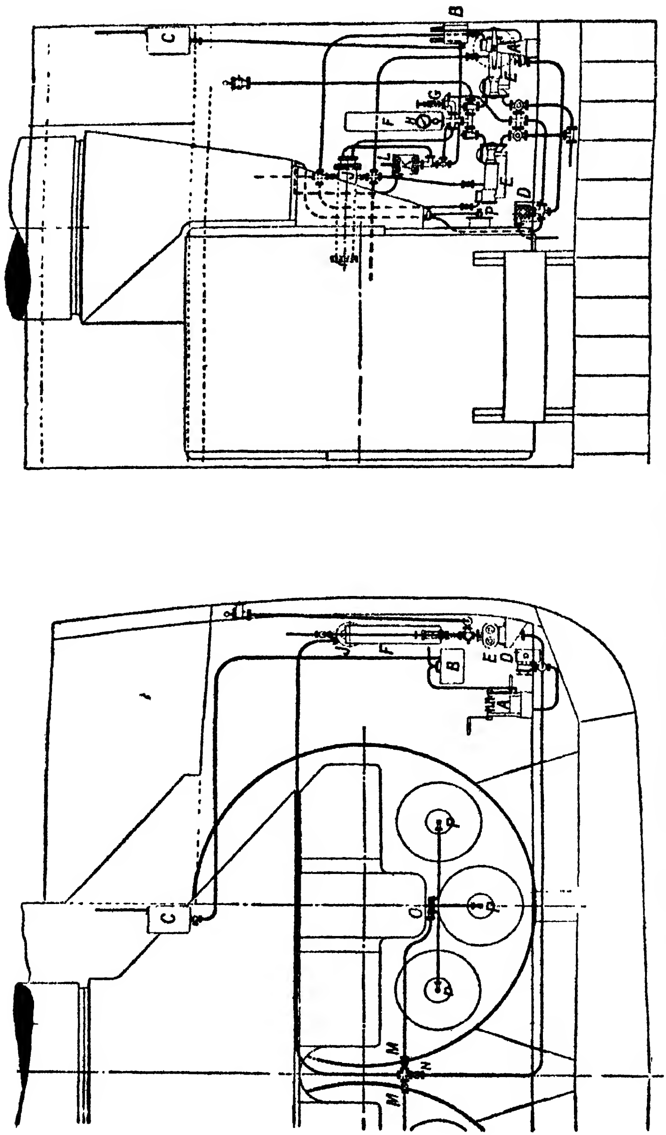


FIG. 68.—Arrangement of marine boilers fitted with Wallsend oil-burning apparatus.

shut-off valves M, distributing valves controlling oil to

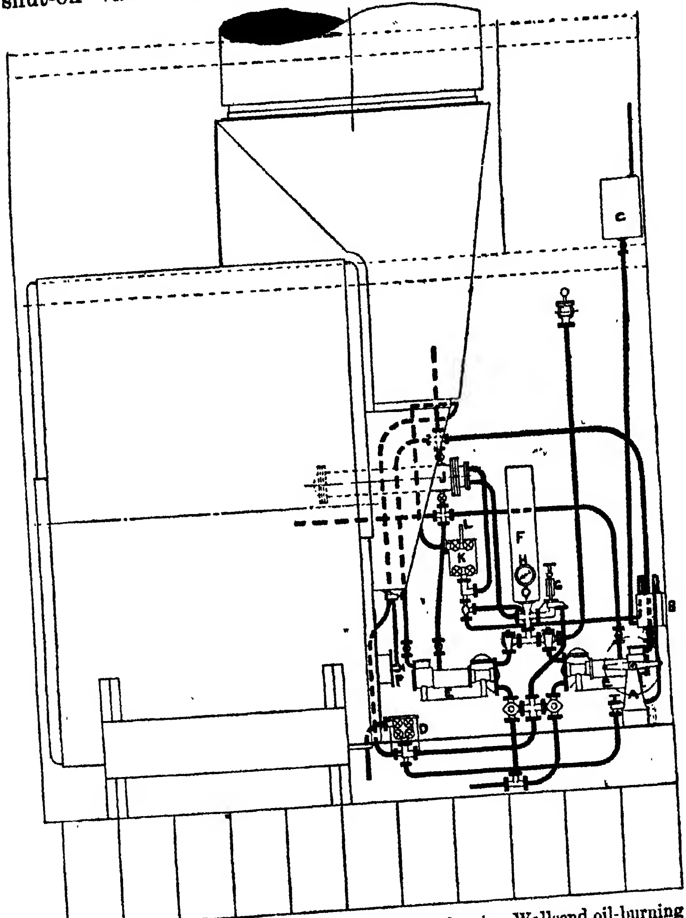


FIG. 69.—Elevation of marine type shell boiler showing Wallsend oil-burning apparatus (duplicate oil-feed pumps, filters, heater, and starting lamp).

various burners O, burners P. Other details include a thermometer L for registering the temperature of the oil,

a pressure gauge P and a discharge filter K of the same construction as the suction filter, each being constructed in duplicate, so that one side may be cleaned without interfering with the regular supply of oil to the furnaces.

Turning now to Continental and American practice, where the fuel consumption of oil- and coal-fired boilers and all steam-driven auxiliaries is, on board ship, in most cases stated in i.h.p. per hour, the following may be accepted as representing average results for natural or forced-draught fired boilers and ordinary triple-expansion engines:—Consumption of oil per hour per i.h.p., 1·02 lbs. and 0·95 lbs. respectively.

Fuel consumption per i.h.p. per hour being the recognised standard for comparison and exclusively adopted, great care is taken to avoid any discrepancy in the observations, recognising that the i.h.p. as calculated from the cards may vary greatly for the *same revolutions*, in consequence of internal losses in the engine itself as influenced by different settings of slide valves, various arrangements of driving auxiliaries, etc., also for the reason that the *working out of a small indicator card easily allows of mistakes being made on either side.*

For instance, it has been found that where in the one case the fuel consumption per i.h.p. amounted to 1·25 lbs., the actual result in speed and fuel consumption per day for the same displacement was considerably better than when the consumption worked out at 1 lb. per i.h.p. per hour, and that the i.h.p. on the indicator diagrams cannot usually be accepted as accurately representing the true power transmitted to the propeller.

The average shipowner does not care so much for theoretical figures as to know the actual consumption of coal or oil fuel per diem in connection with deadweight and speed maintained. These are the figures which define the fuel bill, which he is anxious to keep as low as possible, so that his ship may make a favourable showing in comparison with competitors.

From a number of voyages of the same ship with the boilers burning either coal or oil, and the engines kept

running as nearly as possible in the same condition as regards vacuum, revolutions, etc., it is found that in a ship with deadweight carrying capacity of 7700 tons, the consumption of oil works out over a series of years at about 22½ tons per day against 32 to 33 tons of Welsh coal, or a mean saving, by weight, in fuel consumption of 33 per cent., and as a direct consequence of this, that the ship can carry about 150 to 200 tons more cargo when burning oil.

The sectional and plan arrangement[1] illustrate the Zulver pressure-jet oil-firing system (figs. 70, 71) for mixed firing under natural draught and for oil-firing under forced draught. According to this the two pressure-jet burners b are arranged as shown in the plan view to project two jets to converge at a point some distance in from the front of the furnace. Another point is the method used for regulating and distributing the admission of air; this differs from the methods shown, in that the main supply of air is drawn through an opening in the brick overlay on the grate, a plate p (fig. 70) causing this air to circulate underneath, thus warming it; an auxiliary supply enters at a, and thence to the flame just under the two jets. The main supply is under control by a damper d^1, a second damper d^2 being located at the back of the furnace to regulate admission of air through a flue f direct to the combustion chamber.

In the furnace arranged for forced draught (fig. 71), a similar method is adopted for the admission of air through openings in the fire-brick overlay. Air under forced draught enters at a, and a part of this is admitted through a port controlled by a slide v to an annulus communicating with inlets a^1 surrounding the jets. Under natural draught the flame can be observed through a small annulus surrounding each burner, which, in this instance, are fixed to the fire-door; but under forced draught this is obviously impracticable, and a ferrule m fitted with a mica pane is provided. From the arrangement (fig. 72) it will be seen that the method adopted for feeding the oil to the burners does not materially differ from that shown in figs. 61, 68, and 69, the

[1] *The Marine Engineer and Naval Architect.*

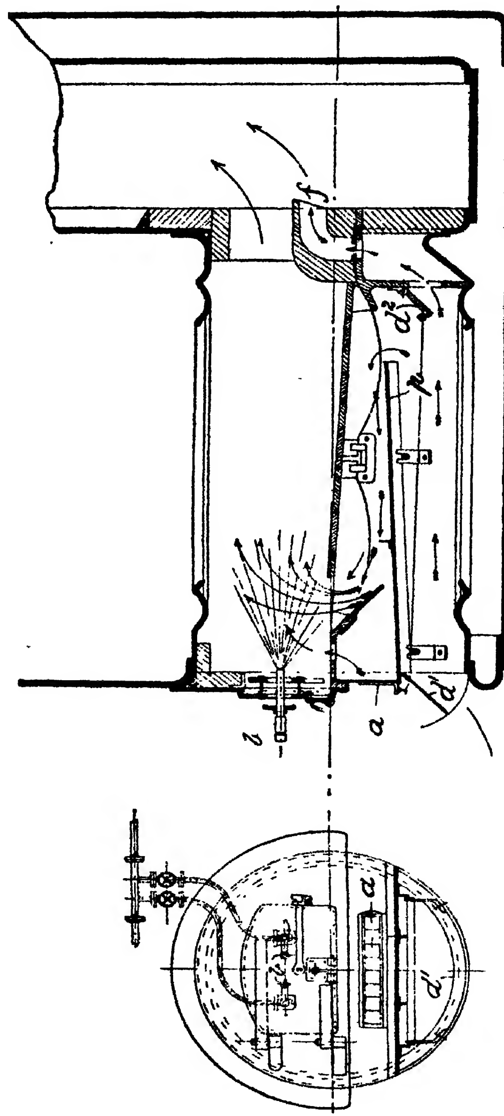


Fig. 70.—Furnace of marine boiler shown arranged for coal- or oil-firing on the Zulver pressure system with duplex burners.

boiler

pumps — steam direct-acting duplex, — as well as the filters and heaters, being provided in duplicate with change-over valves to enable either set to be closed down for cleaning without interfering with the supply to the burners.

In fig. 73[1] is shown a double furnace return flue marine boiler arranged for forced draught on the Howden system previously referred to. Each furnace is fitted with

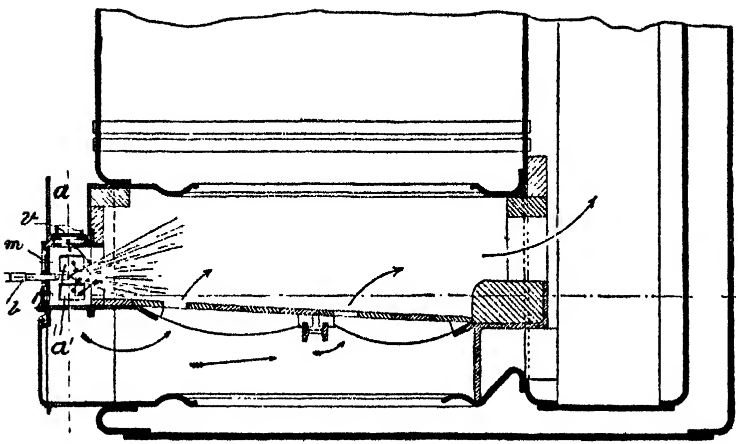


FIG. 71.—Furnace of marine boiler arranged for oil-firing under forced draught.

a pair of Körting pressure-jet burners and fire-brick covered grate, with a bridge at back as in fig. 71; the main difference in this, however—one of the earlier installations,—consists in the method for regulating the air by a valve arranged as shown to slide over the burner.

Turning now to American practice, there is seen to be a very simple method for regulating the air supply to the furnace used in the Moore & Scott oil-firing system with mechanical atomiser; this, as shown by the photo

[1] *Proceedings Inst. Mech. Engineers.*

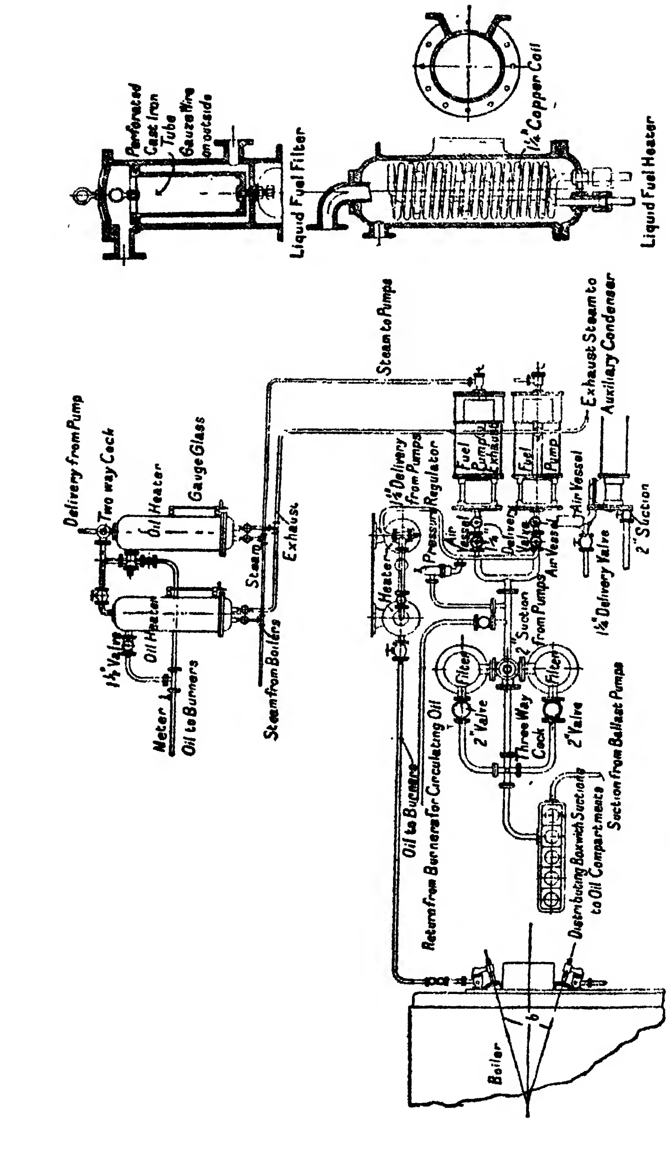


FIG. 72.—Arrangement of oil pumping, filtering, and heating plant for pressure-jet burners, as used on the Zulver system of oil-firing.

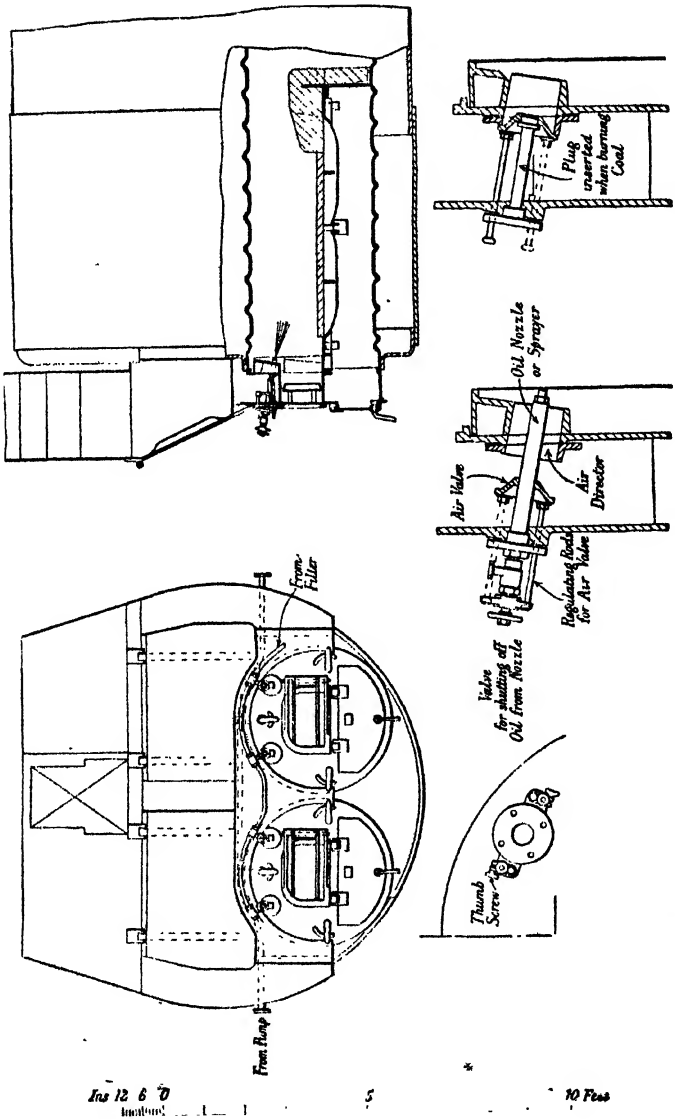


FIG. 73.—Arrangement of combined oil- and coal-fuel installation with Howden's system of forced draught and Körting pressure oil-jet burners.

view (fig. 74) of a marine type boiler furnace, consists of a front p, to which is attached a circular air trunk having lateral openings through which the air is admitted to the furnace, the regulation being effected by a lateral movement of a sliding damper d, by which means just the required volume of air (200 to 250 cubic feet per lb. of oil) can be admitted to obtain perfect combustion; this simple method

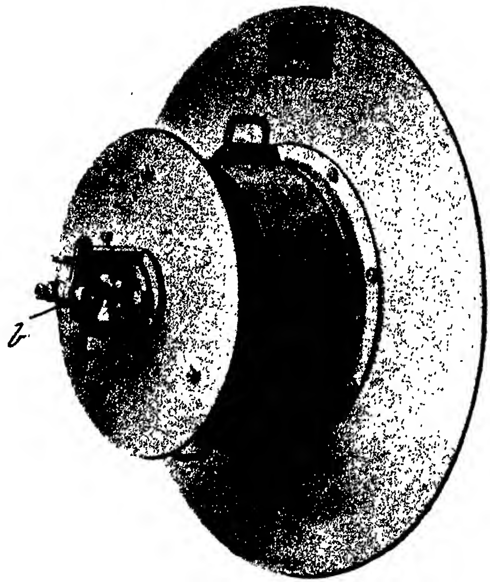


FIG. 74.—Moore & Scott furnace front.

at the same time prevents direct radiation from the furnace into the boiler room. In connection with this oil-burning system a long atomiser (fig. 75), referred to in Chapter VI., is used, consisting of a steel tube t having at the furnace end a nozzle n, and at the outer end a carrier r, with oil inlet f. Inside the jet-box b is a cylindrical plug with three small channels, which are turned obliquely towards the discharge aperture in the nozzle cap n; this atomising plug is integral with a spindle s that passes

through a stuffing-box *g*, and is threaded, and by that means it is possible to adjust the position of the atomising plug with reference to the nozzle tip. This manipulation has an important effect upon the angle of discharge, and consequently upon the flame development—*e.g.* with the plug advanced close up to the discharge aperture this angle is 90°, and can be reduced to less than 60° by a reverse movement, thus leaving a larger space between the atomising agent and the spray aperture.

This method of adjusting the diffusion angle of the spray cone is a decided advance over the fixed angle of spray diffusion produced in a burner of the ordinary construction with rotary jet, and is a very desirable feature in the case of low and narrow combustion chambers, and for furnaces

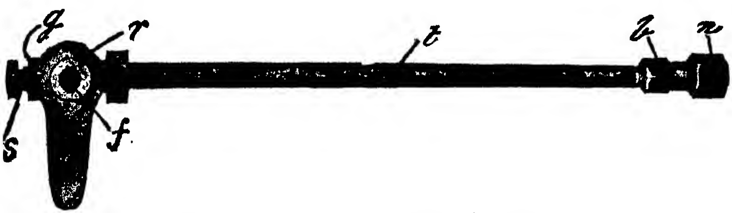


FIG. 75.—Moore & Scott pressure-jet burner.

where a long flame is preferred. The diffusion angle can be varied within the limits stated by a single movement of the atomising plug, thus enlarging or contracting the three small channels named, and by this means obviously varies the resistance and consequently the rate of discharge. Actual tests show that the coefficient of spray discharge ranges from 28 to 45 per cent. under a pressure of 100 lbs. per square inch—*i.e.* from 82 to 132 lbs. of oil per square millimetre per hour, the theoretical discharge of oil of the viscosity tested (Californian) being 294 lbs.

In regard to the most suitable temperature for the oil to be heated, this varies with different oils, those having a paraffin base, and consequently more limpid, require to be heated to a less degree than those having an asphaltum base—*e.g.* Borneo, Mexican, and Californian oils; and with these, only those of less than 15° Beaumè, *i.e.* 0·96, require to be heated above 185° F., as such oils only show a com-

paratively small reduction in viscosity after passing that temperature; but as the amount of steam required for this is very small (*vide* p. 125), and as the critical temperature for least resistance also varies to some extent from time to time for different burners, a temperature of 200° is often exceeded.

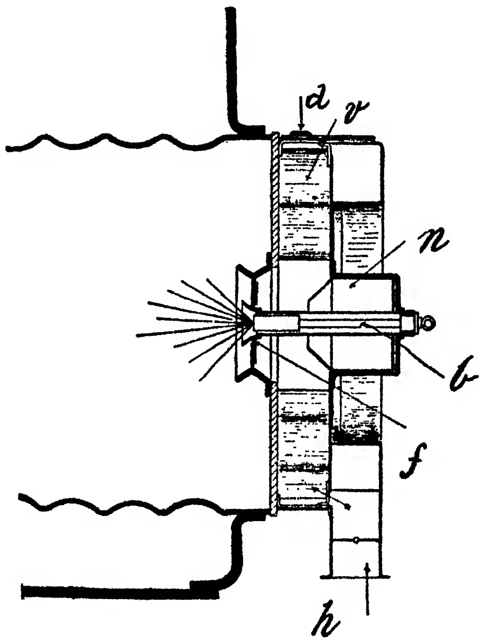


FIG. 76.—Arrangement of furnace for forced draught with White patent burner.

As before pointed out (*vide* p. 44), it is essential for extreme economy with pressure-jet burners that the air supplied to the furnace be not only brought to a high temperature, but closely regulated to the requirements of the burners. In the White system—also of American origin—this aspect has received particularly careful attention, and is effected by forming the furnace front (shown in figs. 76 and 77A) with a multiple series of radial vanes *v*,

which conduct heat from the furnace to the ingoing air; this disposition of the vanes also causes the air to enter the furnace with a vortex movement. The admission is controlled by regulating the distance of the sliding cone *n* from the mixer nozzle *m*, this extending within the furnace to just beyond the flared orifice *f* of the burner *b* (described in Chapter VI., fig. 51). The air can be completely shut off when the burners are not in action, thus eliminating

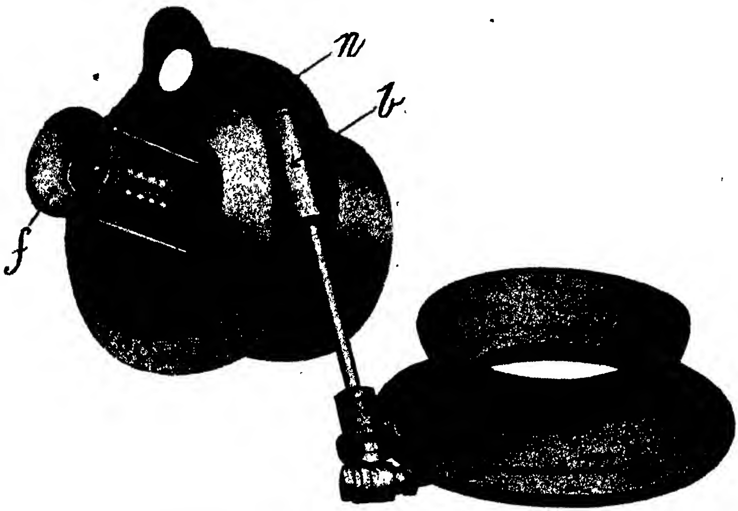


Fig. 77.—Air regulator, burner, and mixing cone used on the White system.

risk of leaky tubes and seams—which is a point of greater importance with oil-firing than with coal.

Oil-burning on the White system has already been successfully applied to quite a large number of tank and cargo boats originally fitted out for coal-burning, as well as to several others formerly equipped for oil-burning on the steam atomiser principle. Particulars of one of these, the *Purus*, 6800 tons, and owned by the Lloyd Brazilerio Steamship Co., will serve to show the comparative advantages of oil-burning on this system. According to extracts from the report of the superintendent engineer, this vessel—

which was originally fitted out for coal-burning—was a hard steaming job, and burned from 26 to 28 tons of coal per day on a speed of 8¼ to 8½ knots and with a very hot stokehold; but since being converted to oil-burning the

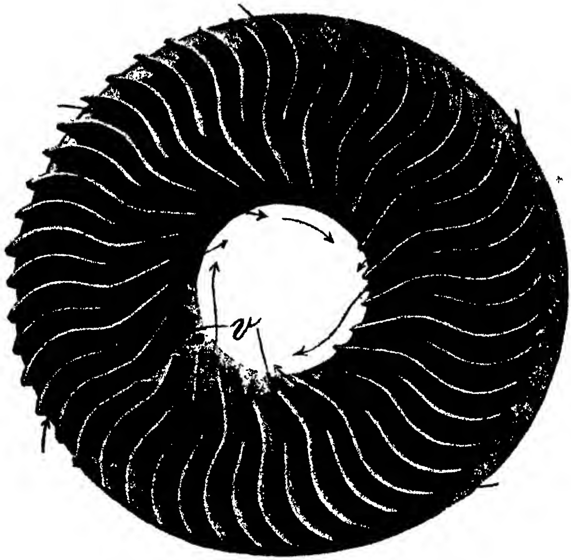


FIG. 77A.—Furnace front used with White patent pressure-jet burner.

consumption has decreased to 17–17·2 tons per day and the speed increased to 9½ knots. Other particulars are as follows:—

Pressure on the oil line when operating . . . (but only 10 to 15 lbs. required to ignite on)	60 to 70 lbs.
Temperature of the oil (two heaters)	225° to 250° F.
Temperature of air at the front end of the mixing cones	220° F.
Temperature of the stack	520° to 530° F.
Temperature of the stokehold	80° F.
Oil consumed per hour	1584 lbs.
Distance covered per ton of oil	15·6 miles.
Distance covered per ton of coal	8·5 miles.
Indicated h.p. with oil	1720
Consumption per hour	0·92 lb. per i.h.p.
Oil used, Mexican	sp. gr. 0·942

The superiority of oil-firing for marine purposes has been proved so convincingly that now it has become quite general practice for all new steam ships to be fitted up with oil-burning apparatus, and for the larger mail and cargo boats to be converted to oil-firing, despite the greatly increased cost of oil fuel, the cost of coal having advanced in a greater proportion. But for the smaller boats the enhanced economy obtained from internal combustion engines shows up the superiority of oil fuel to even better advantage, as will be seen from the following particulars and logs of the running costs of the small pioneer motor ship *Vulcanus* and the steamship *Sabine Rickmers* of equal size, in 1911.

	Vulcanus.	S.S. *Sabine Rickmers.*
Length, B.P.	196 ft. 0 ins.	200 ft. 0 ins.
Breadth	37 ft. 9 ins.	31 ft. 6 ins.
M.D.	13 ft. 2 ins.	18 ft 9 ins.
Draught, S M.	12 ft. $4\frac{1}{2}$ ins.	16 ft. 9 ins.
Block coefficient	·78	...
Deadweight carrying capacity	1235 tons	1269 tons.
Displacement	2080 tons	2290 tons.
Mean speed	8 knots	8 knots.
Engines	6 cyl. 4-cycle, reversible Werkspoor Diesel, dia. $15\frac{3}{4} \times 23\frac{5}{8}$ ins. stroke.	Dias. $17\frac{3}{8} \times 28 \times 44\frac{1}{2}$ ins. $27\frac{7}{8}$ ins. stroke.
Revs. of engines	160 per min.	80 per min.
Consumption per diem	2 tons of oil	11 tons of coal.
Total number of staff and crew	16	30

Vulcanus (European crew) cost per day £6 6 5
Sabine Rickmers (Chinese crew) cost per day £9 0 7

EXTRACT FROM LOG OF M V. "VULCANUS."

Day.	Voyage.	Hours Steaming.	Miles.	Revs. per Min.	I.H.P.	Speed.	Consumption.
1911.	Aug. 3 to 26						
Aug. 5	Kustendje to Hamburg	22–34	177	172	...	8·0	1·95
	Fore 11′ 2″						
,, 6	Draught	21– 2	165	172	...	8·0	1·87
	Aft 12′ 8″						
,, 7		21–33	174	172	...	8·1	1·82
,, 8	Cargo 976 tons	23–45	189	172	...	8·0	1·98
,, 9	Deadweight 1112 tons	24–15	183	172	...	7 5	2·02
,, 10		24–15	184	162	...	7·6	2·02
,, 11		24–14	174	162	...	7·2	2·02
,, 24		23–46	188	170	...	7·9	1·98
,, 25		12– 5	96	170	...	8·0	1·00

EXTRACT FROM LOG OF S.S. "SABINE RICKMERS."

Japan and P. Laut Coal.

Day.	Voyage.	Hours Steaming.	Miles.	Revs. per Min.	I.H.P.	Speed.	Consumption.
1912.	April 22 to 30						
Apr. 22	Pladjoe to Saigon, *viâ* Singapore	8–40	86	85·5	520	10·0	10·5
	Fore 15′ 7″						
,, 23	Draught	19–59	174	85	...	9·1	11·0
	Aft 16′ 5″						
,, 27	Cargo 1033 tons	23 55	208	86·1	...	8·7	13·5
,, 28	Deadweight 1290 tons	23–58	212	86	...	8 8	13·5
	June 20 to 27						
June 22	B. Pappan to Bukum, *viâ* P. Laut	19–50	161	84·5	...	8·1	11·1
	Fore 14′ 3″						
,, 23	Draught	24–14	209	85·3	...	8·6	13·5
	Aft 16′ 3″						
,, 24	Cargo 1013 tons	24–10	201	83·5	...	8·3	13·5
,, 25	Deadweight 1225 tons	24–12	222	84·1	...	9·2	13 5

From these figures it will be seen that the fuel consumption on this small motor-ship averaged just on 2 tons of solar oil per diem, or about one-fifth of the coal consumption of a steamer of like capacity. A striking example of the advantage of such a reduced fuel consumption is to be found in the fact that the vessel completed a voyage of eighty-eight days without bunkering at any intermediate port. On this particular run she left Amsterdam on August 30, 1912, with 140 tons of fuel oil bunkers, loaded a cargo at Constantza, Black Sea, for Cette, proceeded thence to Batoum, and arrived back at Amsterdam on November 27, a distance of some 10,750 miles. In the Bay of Biscay and North Sea, moreover, the *Vulcanus* was confronted by very bad weather. Nevertheless, 6 tons of liquid fuel remained on board at Amsterdam after the voyage. Thus the total consumption was 134 tons in 65·7 steaming days, or 2·03 tons per diem. Having discharged cargo at Amsterdam, the *Vulcanus* was dry-docked, and the engines opened up and cleaned. Beyond a few piston rings no renewals were found necessary, and, after cleaning up, the vessel left Amsterdam on December 19 on a similar voyage.

CHAPTER IX.

OIL FUEL FOR NAVAL PURPOSES.

CONSIDERING how vital a matter the supply of fuel to the vessels of the Royal Navy is, it is not surprising that some considerable deliberation has been taken before deciding on the adoption of oil fuel in place of coal. It is quite fifty years since the first experiments were conducted on behalf of the Admiralty, in experimental trials for the purpose of ascertaining the most suitable oil-burning system for warships and other vessels of the fleet; and now that this has been perfected, other experiments have been carried out to further increase the efficiency of the fleet by burning the oil in the engine direct, instead of in the boiler furnace. But oil fuel does not offer those advantages which a nation richly endowed with coal could take practical account of, for the reason—and a very vital one it is—that the main supply is geographically so far distant. This question of supply is naturally of far greater consequence to the Navy than to the merchant service. A shortage or cutting off of supply, if any political crisis should arrive wherein we were called upon to defend our shores and our commerce, would mean national disaster, if not national ruin; therefore, the supply of oil fuel must be absolutely assured and uninterrupted. Until, therefore, the Burmah, Borneo, Persia, Trinidad, and other fields were brought in, the question, from the Admiralty's point of view, had to remain in more or less abeyance; however, it is only recently that the adoption of oil fuel in the Navy has become a really live question, and the necessary supplies assured. One of the advantages of oil over coal for warships is that a larger amount of heating power can be stored into the space available for fuel, which means that the radius of action

is extended quite 40 per cent., which is a factor of considerable importance in the event of a prolonged absence from port, as well as from a strategical point of view. In fact, coastal destroyers fitted for oil-burning can now, with their bunker supply of 200 tons, steam some 2000 miles at cruising speed in fine weather, and with clean bottoms. As a case in point, the ocean-going destroyer *Swift* can steam from 1500 to 1700 miles without refueling. Speed can also be augmented by the use of oil; smokelessness, again, is another qualification, while the space required for storage may be utilised for fighting power. As these advantages apply equally to our adversaries, this matter must be considered from a purely national standpoint, and not altogether from one of relative cost.

In the experiments carried out by the British Admiralty in 1866, the results were not by any means conclusive or satisfactory, in so far that they did not lead the Admiralty to come to any decision, except that the price of the oil prohibited the adoption of the new fuel; also in that the average quantity of water evaporated during these trials was only 13·2 lbs. per pound of oil consumed. The conditions of combustion appear to have been very imperfect, the tubes showing a very foul condition at the end of the day's experiments. When burnt alone,[1] Burslem oil evaporated 18·38 lbs. of water to the pound of oil; shale oil, 17·92 lbs.; and Torbaine Hill mineral oil, 18·38 lbs. It was not until 1898 that the first successful result with oil-firing was obtained—viz. on the destroyer *Surly*; but from then progress was much more rapid, and soon over a hundred destroyers in the British Navy alone were fitted for oil-firing, twelve being laid down in 1906 for a designed speed of 38 knots, and which were so successful that all the destroyers since laid down for the British Navy have been entirely oil-fired; and while the bunker capacity of the first coastal torpedo-boats was only 20 to 25 tons, this has advanced in stages, first to 90 tons, then to 170, until now the amount of liquid fuel carried exceeds 200 tons. Further, nearly all the pre-Dreadnought battleships carried some 400 tons of oil as an emergency fuel, commencing with those of the *King Edward VII.* class in 1901; while

[1] Calorimeter test.

later ships are all fitted either for both oil- and coal-firing, or for oil-firing alone.

All the great Powers have given serious attention to this matter—America, France, Italy—and have adopted the use of oil fuel in their navies.

The first attempt in oil-firing was made in 1862[1] by the Italian Navy, the method adopted being to mix the residues resulting from the distillation of petroleum with absorbent substances, and to burn this under the boiler on pans or on grooved grates; the results, however, were not satisfactory, owing to the excessive quantity of smoke produced and the irregularity of combustion. With this system of grooved grate—which had the advantage of great simplicity and made it possible to revert easily to coal-firing—the liquid fuel was fed into a series of narrow trough-shaped bars forming the grate, the air for combustion being forced upwards through the grate, and deflected downwards on to the surface of the fuel by T-section bars spaced alternately with the troughs. The results have been satisfactory from the point of view of regularity of consumption, but the quantity of fuel burnt was too high.

The advantages of oil-firing have long been recognised by the U.S.A. Navy, and there have been experiments with liquid fuel dating back as far as 1867. All those experiments confirmed the belief in the considerable military advantages that would accrue from its use; but until recently it had been impracticable to use it extensively on account of the uncertainty as to the adequacy of its supply and the sufficiency of its distribution among the seaports of the world.

Since 1907[2] all U.S. torpedo-boat destroyers contracted for burn oil exclusively, and battleships such as the *Delaware, North Dakota, Florida, Utah, Wyoming, Arkansas, Texas,* and *New York,* contracted for during this period, were fitted to burn oil as auxiliary to coal, each of these vessels carrying about 400 tons of the liquid fuel, to be burned at full power, or when it became difficult to trim coal from the bunkers into the fire-rooms. In the case of these battleships the advantages of oil fuel so appealed to the personnel that this alone was burned to a

[1] *The Engineer.* [2] *The Mechanical Engineer.*

COMPARATIVE DATA OF TORPEDO-BOAT DESTROYERS FITTED FOR OIL-FIRING ON THE SCHUTTE-KÖRTING PRESSURE-JET SYSTEM.

Name of Boat	*M'Call.*			*Burrows.*			*Warrington.*			*Ammen.*					
Speed, knots	16	25	29·5	16	25	29·5	16	25	29·5	12	16	20	25	27·5	29·5
Type of boiler	Thornycroft			Thornycroft			White-Forster			Thornycroft					
Heating surface of boilers, on trial, sq. ft.	4,800	14,400	19,200	4,800	19,200	19,200	9,000	18,000	18,000	4.800	4,800	9,600	14,400	19,200	19,200
Average pressure steam at boilers, gauge, lbs.	240	252	249	254	260	253	248·5	246	246	242	240	260	252	250	250
Specific gravity of fuel oil at 60° F.	·8865	·8865	·8865	·8958	·8958	·8958	·8961	·8961	·8961	·8935	·8935	·8935	·8935	·8935	·8935
B.T.U. of fuel oil per lb.	19,618	19,618	19,618	19,508	19,598	19,508	19,510	19,510	19,510	19,503	19,503	19,502	19,503	19,503	19,503
Lbs. of oil per hour per sq. ft. heating surface	·55	·51	·70	·54	·44	·68	·38	·54	·92	·392	·632	·463	·579	·657	·793
Water per sq. ft. heating surface per hour	6·87	7·05	8·61	6·83	5·37	8·73	3·74	6·21	9·81	4·2	6·7	5·1	6·5	7·44	9·28
Average temperature feed, °F.	216	184	165·9	216	184·3	169·4	190	135	140	70	72	85	62·5	80	163
Fuel oil per knot, lbs.	165	316	453	162	334	442	213	385	562	157	191	222·5	334	459	516
Fuel oil per hour, lbs.	2,640	7,400	13,363·5	2,592	8,350	13,039	3.408	9,625	16,579	1,880	3,055	4,450	8,345	12,630	15,230
Oil pressure at burners	121	120	148	130	105	127·5	204	201	197	125	137	117	104·5	116	128

great extent in port, and to some extent while cruising, although at the installation of the oil-burning equipment these uses were not contemplated.

The *Nevada* and *Oklahoma*, two battleships more recently contracted for, burn oil exclusively. This is perhaps the most radical development in naval engineering since the advent of the turbine. It has permitted in the case of these vessels a reduction in boiler weights, which has made possible the use of heavier armour than has hitherto been employed. The reduction in the length of boiler compartments has permitted the grouping of all boilers under one smoke stack, which, of course, clears the upper deck considerably, and permits more extensive arcs of fire for the turrets.

The apparatus used in a later development of oil-firing as applied to naval purposes in the United States of America is illustrated by figs. 78 and 79; in this the burners B, operating on the pressure-jet principle, and the manner of regulating the supply of air, differ somewhat from the Schutte-Körting burner shown in figs. 41 and 42 *ante*: in that they are arranged in single units instead of in pairs. The burners are comparatively long, and in this respect resemble that shown in fig. 75, but follow the Körting method of imparting a rotary motion to the issuing jet; the helix for this, however, is much shorter and held in place by the nozzle-tip, and at a fixed distance as in fig. 42. A special feature is the means provided for quick removal as shown by the handle H, and the interlocking cam device on the fuel cock C, thereby preventing this without first turning off the oil supply. The air regulators consist each of a large rotary valve A, placed in front of a fire-clay flue F, and are adjusted by a rack gear HI. In fig. 78, eleven burners of this type are shown applied to a Thornycroft boiler, from which the arrangement of feed controls, fuel connections, temperature and pressure indicators will be sufficiently clear without further explanation; further than to add that only one duplex pump is required to supply the fuel feed to a complete set of boilers, and is effected at constant pressure controlled automatically by a diaphragm in connection with the suction end of the pump; a relief valve connected with the suction end of the pump is also

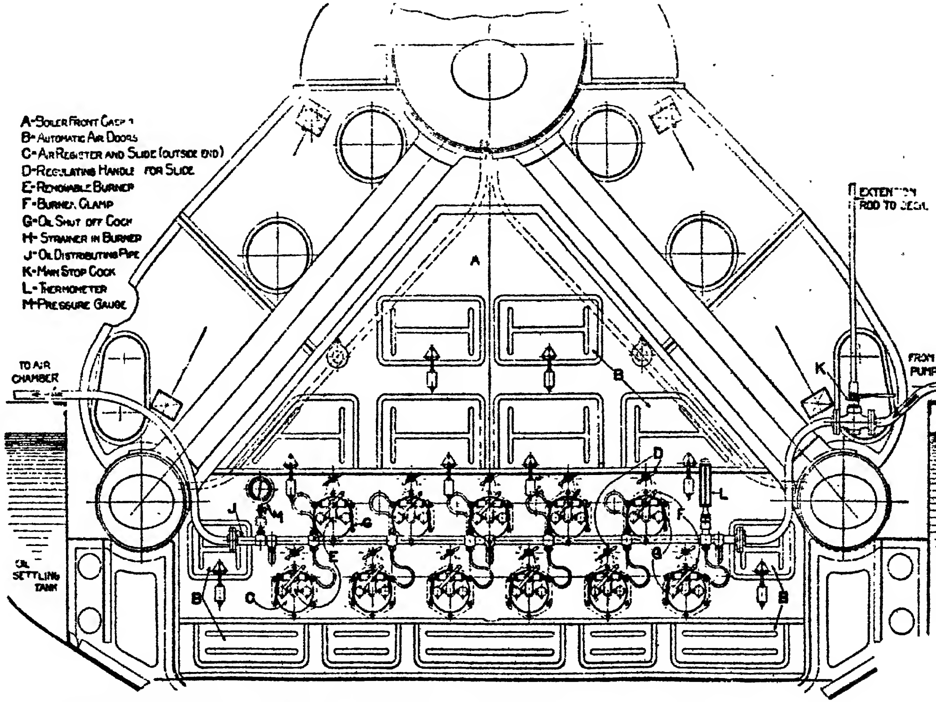


FIG. 78.—Arrangement of Schutte-Körting pressure-jet oil-firing system applied to water-tube boiler.

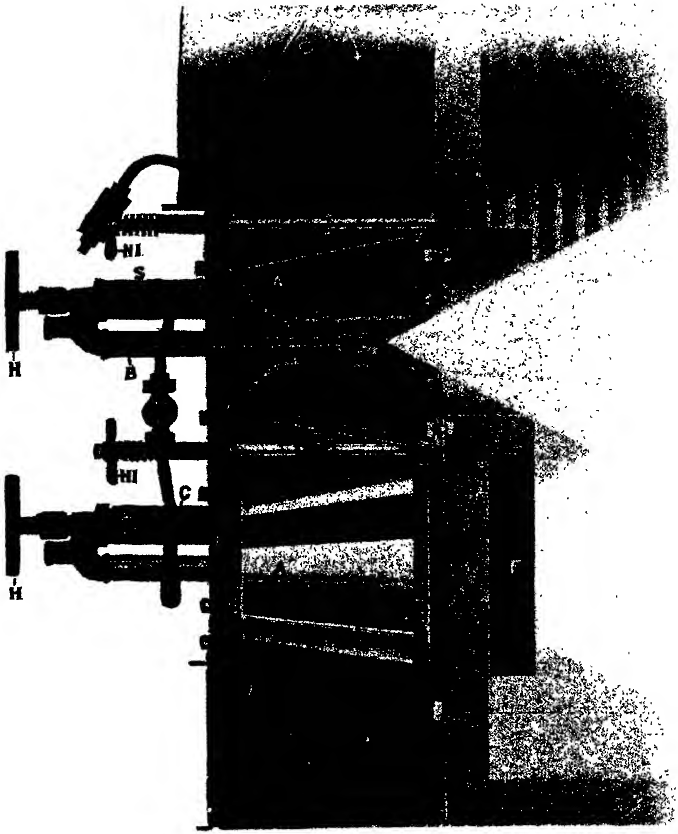


FIG. 79.—Section showing Schutte-Körting burner and air register for U.S.A. destroyer water-tube boilers.

A = Air register.
B = Burner.
C = Oil cock.
F = Fire-clay cylinder.
H = Handle for removing burner.
HI = Handle to operate slides for regulating air supply.
S = Thimble strainer.

provided, so that any number of burners may be set into action or closed down without interfering with the pressure supply to the others. The fuel heater also differs from the usual practice of circulating the oil through a copper coil, and on this system consists of a long inner and outer spiral tube, through the narrow clearance between which the oil is circulated as a film, and in a direction opposite to that of the surrounding steam. The complete equipment of feed pump, heater, and filter is in duplicate, and arranged according to usual practice with change-over valves, besides which each burner is provided with its own filter.

The evaporative duty required from the boilers of destroyers is greater than that stipulated for any other service; and whilst it is possible to burn enough liquid fuel to produce the required duty in boilers hitherto using coal at natural draught, or even coal at moderate forced draught, some difficulty until recently has been found in burning enough oil fuel in boilers of the destroyer type to produce the same duty as that realised under coal at great air pressure. The question of economy of fuel in destroyers when at full power is of comparatively little importance, but the production of the maximum power at short notice is of the most vital importance; however, by methods now adopted this difficulty is solved quite satisfactorily.

The Yarrow Company, years ago, obtained highly encouraging results in two torpedo-boats built by them for the Dutch Government. In these the air pressure for draught in the furnace was only 1 inch on the water-gauge; with the engine stop valve full open, the following were the observed results: boiler pressure 150 lbs. to the square inch; pressure in the first receiver 54 lbs., and in the second receiver 5·5 lbs.; vacuum 23½ inches; and revolutions 340 per minute; under which conditions a speed of 24·5 knots was obtained. Oil fuel was then started, and as much oil burnt as possible without making smoke, the coal consumption being at the same rate as before. The results were then as follows: boiler pressure, 180 lbs. per square inch; first receiver pressure 64 lbs., and second receiver pressure 9 lbs.; vacuum 23¼ inches; and the revolutions 365 per minute; the resultant speed being 26½ knots.

Thus, by turning on the oil feed the speed was increased by just 2 knots. Moreover, this increase was obtained almost instantaneously, or, at any rate, within a few seconds of the oil being turned on. Borneo oil was used, and the supply for the two boilers was at the rate of 700 lbs. per hour. The coal burnt per hour was at the rate of 2800 lbs., both when coal alone was used and when it was burnt in combination with oil. The oil supply tank had a capacity sufficient for a run of an hour and a half under the above conditions of working, and was placed on deck, so that, if it should be pierced by shot and the oil escape, it would simply run into the sea.

One of the earliest apparatus employed in the French Navy for burning liquid fuel was the Ferrari, in which system longitudinal trays were used, containing wicks separated by screens so arranged as to distribute the air; a tube pierced with holes placed beneath each wick distributed the oil throughout its whole length. Two series of trials were made at Toulon with this apparatus, on the *Amalia* and on a torpedo-boat. The object in this case was only moderate firing, and on a trial in dock the consumption was stated to be 2·12 lbs. of oil per horse-power per hour, and at sea 1·79 lbs. compared with the coal consumption of 3·22 lbs. The results of the trials on the torpedo-boat were, however, not so satisfactory. The burner originally used in the French Navy, and first tried on board the *Baffle* and a torpedo-boat, was that known as the Guyot. In this burner a steam jet was regulated by the movement of a central spindle, which also regulated the oil supply. Although it is easier to regulate the steam in this manner, great care is required in order that the spindle shall remain perfectly in alignment with the spray nozzle. It is also important that the spindles be not too long, and they never project beyond the steam jet.

On the torpedo-boat 11·56 to 11·58 lbs. of water were evaporated per pound of fuel oil, and in some early trials in France (1887) 1·2 lbs. of steam were required for each pound of oil atomised. On the *Baffle*, which has already been referred to, the consumption was ·75 to 1 lb., and on the torpedo-boat 1·2 lbs. In the trials made with the Guyot burner in 1895 the consumption is said not to have

exceeded ·65 lb., and even dropped as low as ·63 lb. of steam per pound of oil consumed in the burners.

In Italy similar results, varying from ·5 to ·25 lb., were obtained, and on a Schickau torpedo-boat only 1·02 lbs. of steam is said to have been required. It may be taken for granted that on an average not more than half a pound of steam is required for atomising a pound of oil (*vide* pp. 122–123). But, of course, at sea the fresh water has to be obtained by distillation, and partly from this reason, and partly owing to the lower evaporative power of a steam spray burner, the use of steam in both the British and Foreign Navies have been definitely abandoned for the purpose of atomising the spray of liquid fuel injected into the furnace. Experiments with a D'Allest burner carried out in 1887, showed an evaporation of 11·33 lbs. per pound of oil used; and in 1890, in the French Navy, on the torpedo-boat already referred to, 11·36 and even 13·25 lbs. of water were evaporated, and the Guyot burner evaporated 12·5, 12, and 11·3 lbs. in a closed stokehold and under an air pressure of ·31, ·67, and 1·8 inches respectively. Thus it was then with a steam-jet burner equally easy to evaporate 12 lbs. of water with oil, as 9 lbs. with a corresponding amount of coal. It will be noted, therefore, from these earlier experiments with oil-burning apparatus actuated with the aid of a steam jet, that the evaporative efficiency was much below the results now obtained with the latest form of pressure-jet burners, and also with burners using a jet of heated air under slight pressure, *i.e.* from 1·5 to 4 lbs. per square inch (*vide* pp. 124–125).

In the Italian Navy steam-jet atomisers of the Cuniberti, Nabor Soliani, and Frugoni types (*vide* fig. 19) have also been largely used for warships; the latter also on the U.S.A. battleship *Delaware*. According to Captain Gianelli,[1] of the Italian Corps of Naval Architects, almost any type of boiler can be adapted for burning liquid fuel; but those boilers are preferable which have a long flame-path, and in which the heating surface in direct contact with the flames is not too great. An ample combustion chamber is of special importance, for upon its capacity depends the quantity of fuel that can be burnt. The

[1] *The Engineer.*

length of the furnace is not so limited as in a coal-fired boiler, 4 metres (13 feet) being considered a favourable limit of length. Tests have shown that 8 h.p. can be obtained per square metre (about 0·8 h.p. per square foot) of heating surface. With water-tube boilers having an ample combustion chamber, a rational flame-path, and good burner, 6 h.p. per square metre (about 0·6 h.p. per square foot) of heating surface can be reckoned upon; but that, in order to secure a high efficiency, the point of formation of the flame should be at a distance from the heating surface. Also for the liquid fuel to burn completely, it is necessary for atomising to take place in a strong air current, and forced draught be resorted to.

One of the main difficulties in liquid-fuel firing is the accurate regulation of the fans to give the exact amount of air required; an excess of air cools the furnace, whilst insufficiency of air causes a part of the oil fuel to remain unburnt, giving rise to smoke. In order to facilitate regulation and to force combustion without any excessive production of smoke it is essential to use powerful fans, giving at least a pressure of from 80 mm to 100 mm. (3 inches to 4 inches) of water column. With steam-jet atomisers firing can take place at low rates of steaming without fans and without smoke production, which is an advantage.

However, pressure burners are now found to meet with the greatest favour, since, besides doing away with the water consumption which forms a necessary feature of those using a steam jet, they work more perfectly, and are most easily operated. In fig. 80 is illustrated the method of fitting the Thornycroft pressure-jet burner to a water-tube boiler; in this the air enters between a series of cylindrical trunks telescoping one within the other. According to this system a burner, as described in Chapter VI. (fig. 47), is used in connection with a pair of vertical simplex fuel feed pumps, a horizontal tabular heater, and two pairs of filters. With this burning apparatus when fitted in conjunction with Thornycroft boilers of latest design and of fairly large size, the makers are prepared to guarantee an equivalent evaporation of at least 16·5 lbs. of water, from and at 212°, per pound of oil

per hour, if the rate of evaporation does not exceed 4 to 5 lbs. per square foot of grate surface.

Theoretically, 1 lb. of fuel oil is capable of evaporating 20 lbs. of water from boiling point, and, as with oil-firing on the hot-air-jet system, 15·5 to 16·5 lbs. of water can be evaporated per pound of oil under practical working conditions, thus showing an efficiency from 78 to 83 per cent. of the theoretical calorific value; and with forced draught under ordinary working conditions using the pressure-jet system, an efficiency from 79 per cent. to 81·25 per cent. can be obtained. That is to say, with oil fuel of 19,320

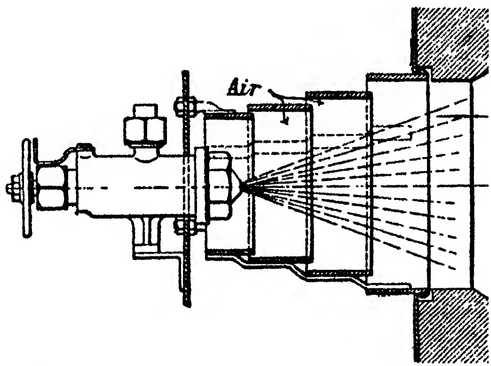


FIG. 80.—Arrangement of Thornycroft pressure-jet burner and air regulator.

B.T.U.'s per pound, the evaporation would be from 15·8 to 16·25 lbs. of water per pound of oil consumed. Also, the steam-jet system will recover from 67 per cent. to 78 per cent. of the calorific value of the fuel used, or a pound of oil fuel will evaporate from 13·4 to 15·5 lbs. of water.

Since, however, it has been ascertained by prolonged trials under ordinary and test conditions that the pressure-jet system with forced draught will work with as high an efficiency as the air-jet (*vide* p. 124), this is consequently now considered to be most suitable for naval purposes owing to the less space required, a conclusion that is all the more obvious when it is remembered that an oil pump is necessary for either system; and further that, volume for volume, the amount of air that has to be compressed (in

order to give pressures from 5 to 30 lbs. per square inch) must be at least 1000 to 1600 times greater than the amount of oil to be burnt, and with some burners this proportion

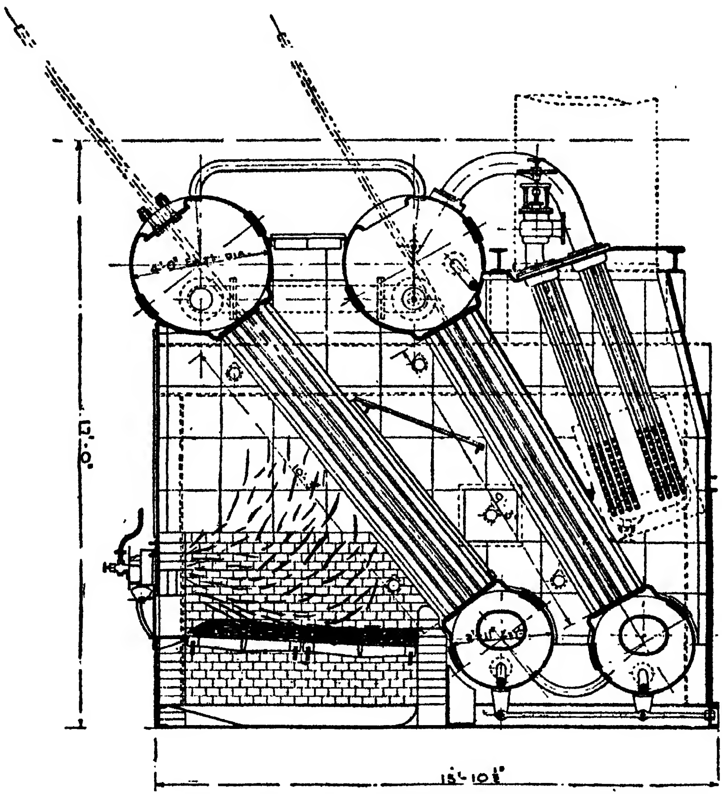


FIG. 81.—Clarke-Chapman marine-type water-tube boiler, fitted with Wallsend oil-burning apparatus for firing with mixed coal and oil fuel.

rises to as high as 3000. The weight of air is also from 3 to 5 times greater than that of the oil; but the difference in the steam required is enormous, that for the air jet being at least 3, and often 5, times greater than for the pressure jet, leaving out of consideration the difference in

the space occupied, complexity of the mechanism and pipe connections, all in favour of the pressure-jet system of oil-firing. In this is included the steam requisite for the heaters, in order that the temperature of the oil may be raised from normal to 220 to 270° F., which is necessary for the efficient working of all pressure-jet burners (*vide* p. 149).

The necessary apparatus for applying this system to a battery of marine type water-tube boilers may be gathered from the examples, figs. 78, 81, 82, and 83, the first of which illustrates a Thornycroft boiler arranged with Schutte-Körting pressure burners; the second, a Clarke-Chapman boiler provided with Wallsend burners to work on the pressure oil system; while the third and fourth examples illustrate water-tube boilers of the Yarrow type, one fitted with apparatus on the Wallsend, and the other on the Kermode system of oil-firing with pressure-jet burners.

In regard to mixed firing, Bertin of the French Navy states that the main advantage of mixed firing lies in being able to obtain at will a large increase in the power of the boilers, as the combustion of liquid fuel does not in any way prejudicially affect that of coal. It is therefore not correct to consider the evaporative power of coal as identical when passing from ordinary to mixed firing. Admitting this as a principle, and supposing the quantity of water evaporated by the coal to be constant, the extra evaporation due to the better mixing of the gases is credited to the oil fuel. As a case in point:—On the *Furieux*, after a trial with coal alone, when 18·8 lbs. of coal were burnt per square foot of grate per hour, two trials were made of mixed fuel with different proportions of oil, when 21·3 and 21·7 lbs. of mixed fuel were burnt. The results of these trials, which were carried out under similar conditions, are as follows:—

$\frac{p}{c}$	a	x	$\frac{x}{a}$
	lbs.	lbs.	
0·00	9·05	...	...
0·45	9·05	11·34	1·25
0·64	9·05	14·12	1·56

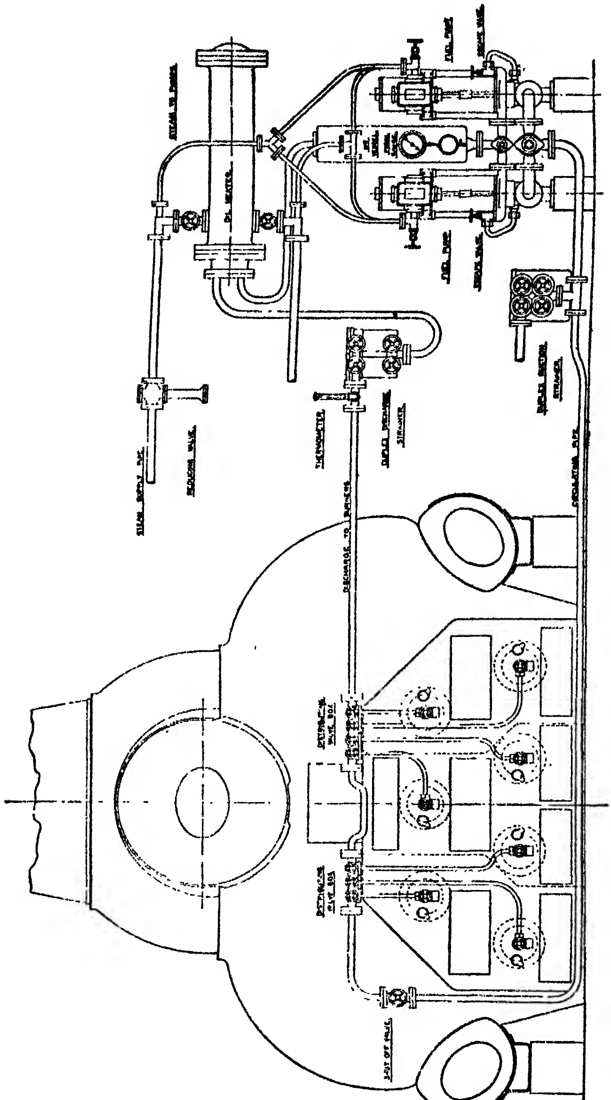


FIG. 82.—Arrangement of seven Wallsend pressure burners, duplicate fuel pumps, filtering apparatus, and oil heater, shown applied to a Yarrow-type marine boiler.

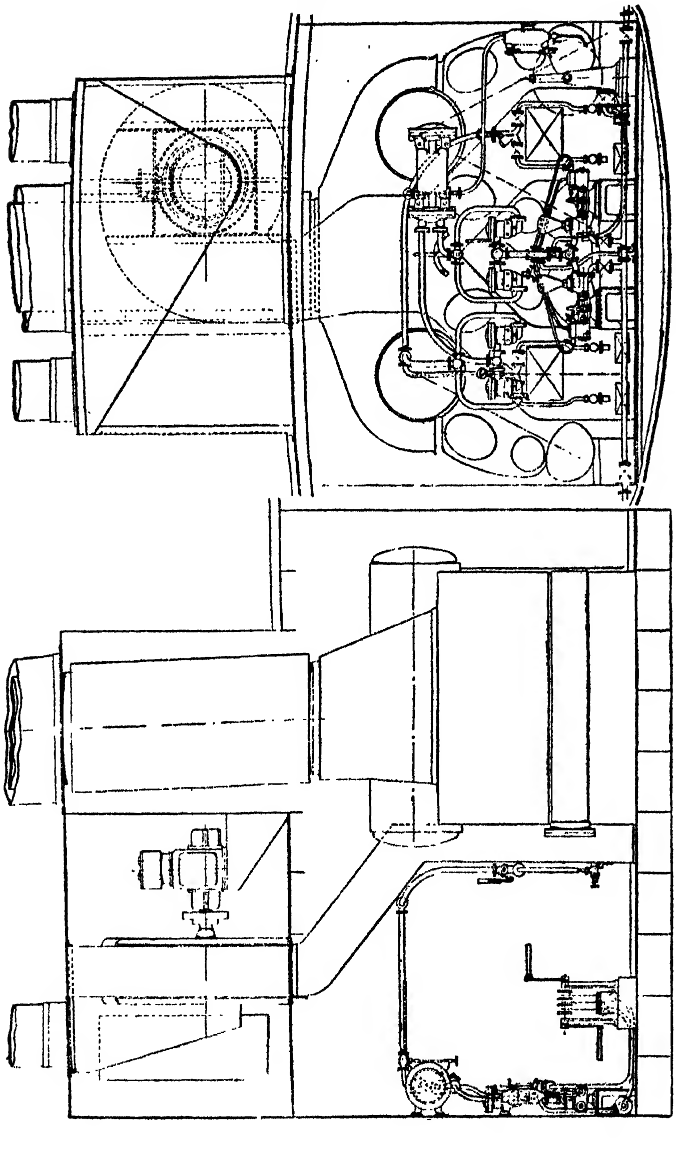


FIG. 83.—Midship sections showing arrangement of Kermode oil-burning apparatus (pressure-jet system) for Yarrow marine boilers.

In the last trial, the efficiency for oil fuel when burnt in conjunction with coal is higher than when burnt alone. This ought to be the case under favourable conditions with mixed firing, but it is not always so. On a trial at Cherbourg, with mixed firing and Godard boiler, transformed for mixed combustion, with a high rate of forced draught and oil burners not properly arranged in the furnace, the efficiency b was inferior to that of a for coal alone. Although actual evaporative trials are scarce, combined engine and boiler trials, giving the consumption per horse-power with mixed firing or with coal alone, are, on the other hand, plentiful. These trials may serve as bases of comparison, always assuming that the calorific value of the coal remains constant.

If C be the consumption of coal per indicated horse-power when burnt alone, and c and p the consumption of coal and oil per horse-power when mixed, the quantity of oil p, which will produce 1 h.p. per hour, will be $C-c$, and as the calorific efficiency is inversely proportional to the amount of coal necessary to do a given amount of work, we have

$$R=\frac{C-c}{p}.$$

This formula only holds if the two trials, alone and mixed firing, were carried on at not too high a rate of forced draught. Generally, a high rate of forced draught is not favourable to the use of oil fuel, and the ratio of p to c should be decreased as the rate of combustion increases, if the efficiency R is to be greater than 1, that is to say, if mixed combustion is to show a gain over the combustion of coal alone. There must exist for each rate of forcing a ratio between p and c which corresponds to the minimum value of the total consumption per horse-power, $p+c$, and another ratio corresponding to the maximum horse-power that can be developed. The number of complete trials that have been made is not sufficient to determine definitely the laws relating to mixed firing; the following table, however, which is a *résumé* of trials made with a locomotive boiler on a torpedo-boat, may be consulted with interest:—

	1st Series.	2nd Series.	3rd Series.
Air pressure— ins. of water	0·6, 0·51, 0·47	1·0, 1·0, 1·14	1·97
Coal alone— lbs. per h.p. hour, c	2·99, 2·99, 2·99	3·02, 3·02, 3·02	3·37
Coal— lbs. per h.p. hour, c	2·19, 2·04, 1·30	1·59, 1·61, 1·46	2·72
Petroleum— lbs. per h.p. hour, p	0·85, 0·87, 1·10	0·90, 1·06, 1·46	0·97
Total— lbs. per h.p. hour, $p+c$	3·04, 2·91, 2·40	2·49, 2·67, 2·92	3·69
$R=\frac{C-c}{p}$	0·94, 1·09, 1·53	1·58, 1·33, 1·07	0·67

The above table shows that fairly good results can be obtained with natural draught, or at very moderate rates of forcing, when burning slightly less oil than coal. Thus, with natural draught, when burning 16·4 lbs. of coal per square foot of grate per hour, on a combustion of 12·3 lbs. of mazout with an efficiency of 1·5, the same power would be developed as when burning 34·8 lbs. of coal. Under these conditions, mixed firing may, in some cases, replace forced draught, over which it has some advantages.

Probably the most exhaustive naval tests which have been made, were those conducted in 1902 by the United States Navy Board, under the direction of the engineer-in-chief of the U.S. Navy. The conclusions which were arrived at during these trials are sufficiently important to find a place in this book (*vide* Chapter VII.), where they are quoted at some length, not only because they form a reliable record of naval practice, but because they bring out certain important points connected with the use of liquid fuel on warships. The results of the steaming tests are also given, together with descriptions of the burners employed.

The numerous experiments that have been made by several naval powers during the past forty years in the attempt to use oil as a fuel, show how important this question is regarded by military experts. It is now plain why success was not at first attained. There was too much effort exerted to burn oil in the same manner as

coal. It is now realised that the oil should be atomised (it is impossible to completely gasify it) before ignition, and that the length of the furnace, the volume of the combustion chamber, and the calorimetric area are factors which must be considered. In fact, it is highly probable that it may be found advisable to design a special boiler for burning oil.

The more the liquid-fuel question is investigated, the more specialised seems the problem of successfully installing an oil-fuel appliance on board a battleship. For the army transport service it has proved very desirable, since a supply of oil can be maintained at the several calling ports. In regard to the installation of oil-burning apparatus on large-powered battleships and armoured cruisers, there are three distinct features which must be considered, viz. the mechanical, commercial, and the structural. Regarded from two of these view-points, it seems as if "coaling ship" will eventually cease to be an operation upon the war vessel.

While both naval and mercantile vessels traverse the ocean, there is a wide difference in their construction as well as in the nature of the duty performed, and this must be taken into account in designing the motive plant.

The problem that confronts every designer of a warship is the combination of the greatest speed, armament, and ammunition supply, protection, and range of action, in the smallest and least expensive hull, and any reduction of weight and storage room necessary to any of these qualities is a saving which acts and reacts favourably upon the problem in a manner familiar to us all. The practical figures of comparison between coal and oil fuel realised in recent practice are that 2 tons' weight of oil are equivalent to 3 tons' weight of coal, and 36 cubic feet of oil are equivalent to 67 cubic feet of coal as usually stored in ships' bunkers; that is to say, if the change of fuel be effected on an existing war-vessel or applied to any design, without changing any of the data other than those affecting the range of action, the latter is increased by 40 to 50 per cent. upon the bunker weight allotted, and 80 to 90 per cent. upon the bunker space allotted. Coal protection, whatever its real advantages—a matter upon which different

opinions exist,—will *per contra* disappear, liquid fuel being stored below the water-line; but the double bottom and other spaces—hitherto quite useless, except for water storage—will then be capable of storing liquid fuel, and the space now occupied by coal bunkers be available for other uses.

Apropos to the advantages of oil fuel over coal for naval vessels, it may be stated here that the evaporation per pound of fuel is in the ratio of about 14 to 9, and per square foot of heating surface in about the ratio of 10 to 8. Oil fuel also can be taken aboard more rapidly, without manual labour, and without interruption to the routine of the ship. The problem of fueling at sea may therefore be considered as solved, it now being quite feasible for a warship even in mid-ocean in ordinary weather to rebunker 300 tons an hour from a tank steamer alongside. Steam for full power can be maintained as readily as for lower power. A vessel burning oil is capable of steaming at full speed for a distance limited only by the supply of the fuel. There is no reduction in speed due to clinkered grates or to difficulty in trimming coal from remote bunkers, or to exhaustion of the fire-room force. There are no cinders, and the amount of smoke can be controlled. A considerable reduction in personnel is possible. The weight and space required for boilers is reduced: first, by the reduction in heating surface required, and, second, by the shortening of fire-rooms. Consequent on the reduction in heating surface is a decrease in weight and cost of boilers. Coal and ash-handling gear is eliminated. This renders unnecessary the piercing of the hull for coal trunks and discharges from the ash expellers or ash ejectors. The stowage and handling of oil is much easier than of coal, and results in a much cleaner ship, with consequent increase in time available for drills. The mechanical supply of fuel to the boilers gives a prompt and delicate control of the steam supply, permitting more sudden changes in speed than with coal, which is a tactical advantage.

In regard to the use of oil fuel for naval purposes, the following abstracts from a statement made in 1913, by the British Admiralty, clearly show to what an extent oil-firing had already been adopted in the British Navy:—In the

year 1909 the first flotilla of ocean-going destroyers wholly dependent on oil was created, and each successive year since then another flotilla of destroyers burning oil only has been built. There were then built and building more than 100 destroyers, including coastal destroyers, solely dependent on oil fuel. Similarly, during the period 1908-1913, oil had been employed in coal-burning battleships and cruisers, to enable them to realise their full power in an emergency, and towards the end of the year 1911 there were more than 150 vessels built and building which were dependent wholly or partly on oil fuel.

It was not possible for fast battleships to be made capable of steaming at the necessary speed, having regard to all their other qualities, on a coal basis without inflicting extraordinary hardship upon the personnel and sensibly increasing the length, and consequently the cost, of those vessels, which is already greater than that of any other vessels built. To increase the length and the present dimensions would raise the whole docking problem in a new and most formidable shape. Further, the light-armed cruisers simply could not be constructed on a coal-burning basis; they would either have to be greatly increased in length and displacement, in which case they would become too expensive for the number and the service required, or else they would lose from 3 to 4 knots of speed, and consequently be unfit for the tactical duties for which they were designed. Oil has been the only fuel for destroyers since 1909, and the increasing speed of these vessels renders them all the more dependent on its use; oil is now the only fuel used in the British Navy and to an increasing extent in all Foreign Navies.

The use of oil fuel instead of coal makes it possible in every type of war-vessel to produce a ship which will fulfil given conditions of speed and armament, of lesser dimensions and consequently at smaller cost than could be done with coal. But further than this, the great advantages which liquid fuel presents in solving the problems of our naval design make it possible to obtain vessels of very high speed compared with their dimensions —of a speed, that is to say, compared with their dimensions which could never be attained if coal remained the only fuel.

As regards the question of supply, it may be more expensive if not difficult to transport and to store oil than coal. The fumes of all petroleum compounds have great searching qualities, and therefore precautions have to be taken to guard the storage tanks. But as a set-off against this statement, the British Petroleum Co., for instance, keep a store of over a million tons near the Albert Docks on the Thames; then again the Anglo-American Oil Co. have a like amount in tanks at Purfleet, besides other stores, at Avonmouth, Hull, Barrow-in-Furness, Grangemouth, Manchester, Sunderland, Dublin, and several other places; besides which there are several other oil transport companies. The British Government, too, have established a large number of storage tanks in the Medway, the Humber, at Dagenham, Invergordon, Cromarty Firth, Rosyth, Portsmouth, Dundee, Dover, Portland, Pembroke, Haulbowline, and elsewhere; in addition to which, from many of these depôts pipe lines are laid to other storage tanks further inland—*e.g.* to Selby and from Dagenham. In regard to transport, what with the large number of oil-fired and motor-driven tank ships that have been built during the last few years for the various transport companies, now exceeding 350, and mostly British, besides others owned by the Government, the question of supply to this country, even if entirely dependent on outside resources, is not so serious a military problem as it has been regarded.

In regard to the density, flash point, viscosity, and freedom from impurities required of oil fuel for naval purposes, the 1910 standard adopted by the British Admiralty specified a flash point of 200° F. (close test), and that the oil should flow under a 2-feet head through a ½-inch copper pipe 3 feet long arranged horizontally, and at a temperature of 32° F.; that the oil should contain only 0·75 per cent. of sulphur, 0·5 per cent. of moisture, and only a trace of acidity. Whereas in the 1912 specification, the flash point has been lowered, and the sulphur contents allowed made higher, in order to cover a number of grades of Mexican and other oils. Lloyd's are also, under their revised regulations, recognising a flash point as low as 150° F. The new specification (1912) is as follows:—

Quality.—The oil fuel supplied shall consist of liquid

hydrocarbons, and may be either (*a*) shale oil, or (*b*) petroleum as may be required, or (*c*) a distillate or a residual product of petroleum, and shall comply with the Admiralty requirements as regards flash point, fluidity at low temperatures, percentage of sulphur, presence of water, acidity, and freedom from impurities.

The flash point shall not be lower than 175° F., close test (Abel or Pensky-Martens).

The proportion of sulphur contained in the oil shall not exceed 3·00 per cent.

The oil fuel supplied shall be as free as possible from acid, and in any case the quantity of acid must not exceed 0·05 per cent., calculated as oleic acid when tested by shaking up the oil with distilled water, and determining by titration with deci-normal alkali the amount of acid extracted by the water, methyl orange being used as indicator.

The quantity of water delivered with the oil shall not exceed 0·5 per cent.

The viscosity of the oil supplied shall not exceed 2000 secs. for an outflow of 50 cubic centimetres at a temperature of 32° F., as determined by Redwood's standard viscometer (Admiralty type for testing oil fuel).

The oil supplied shall be free from earthy, carbonaceous, or fibrous matter, or other impurities which are likely to choke the burners.

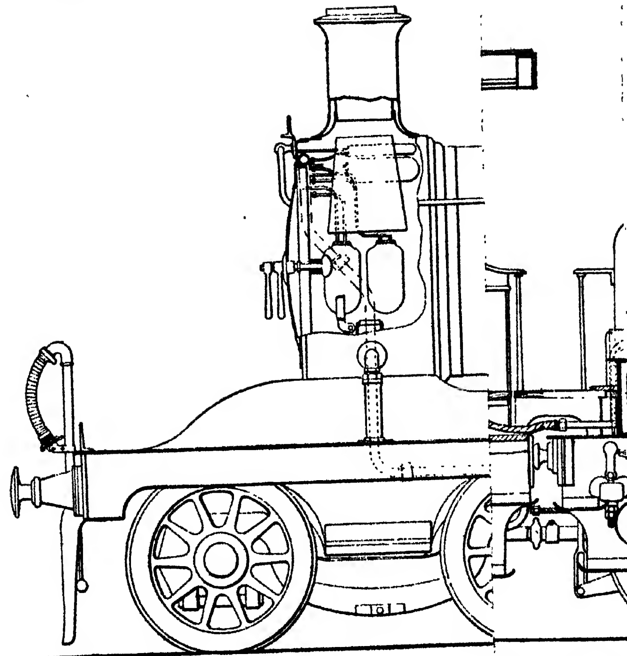
The oil shall, if required by the inspecting officer, be strained by being pumped on discharge from the tanks, or tank steamer, through filters of wire gauze having 16 meshes to the inch.

CHAPTER X.

OIL FUEL ON LOCOMOTIVES.

THE use of oil fuel on locomotives has made an earlier advance, so far as the practical and economic results obtained, than in marine work, although in the latter, as has been indicated, liquid-fuel practice has made great advances. Very close and continuous attention has been given to its application to railway work by many engineers, notably Mr James Holden, the late locomotive superintendent of the Great Eastern Railway—the outcome of whose effort and application has resulted in the development of an oil-burning system which, if not the most efficient and most economical available, stands in the forefront in the use of oil fuel for locomotives. Progress, however, at first has been comparatively slow in this direction; but now there is scarcely a single country in Europe that has not its liquid-fuel locomotives, while oil fuel has been adopted in India, Egypt, Japan, and, of course, America—both north and south, especially in the western States,—also in Canada, as it is reported from Vancouver that, following out the policy announced early in the year 1913, the Canadian Pacific Railway is converting locomotives in its Vancouver-North Bend service into oil burners, and establishing oil tanks on the route to supply the fuel for the locomotives, and while oil has been used for some time on this line it is planned to extend the system to other sections.

To illustrate the present arrangement of the Holden apparatus, a general outline elevation of one of a type of single-driver Great Eastern express locomotives is



fitted with Mr H

presented (fig. 84), the description of which is as follows:—

A. Patent burners of the construction shown in detail in figs. 15, 15A, 16, and 17.
B. Steam fitting supplying dry steam from the dome to the burners.
C. Regulating valves operating singly or together.
D. Oil-fuel pipes conveying the fuel from the tank on the tender to the burners.
E. Oil-fuel tank.
F. Warming coil used in cold weather to keep the oil fuel sufficiently liquid to regulate easily.

The oil fuel is injected through the front nozzles in a semi-sprayed condition by steam admitted from one of the fittings. The jet supplied by this is of annular formation, and induces hot air through the interior from the heaters in the smoke-box. To complete the atomising of the fuel, a secondary supply of steam issues from a series of fine jets arranged round a hollow ring just behind the nozzle. These jets induce a considerable volume of free air which varies according to the velocity of steam permitted to pass the regulating cock, and is injected at angles to deliver the atomised fuel equally over the grate area.

At the International Railway Congress held at Paris in 1900, Mr Holden stated that the most desirable position of the burners could only be arrived at by long-continued experiments, and so far the best results have been obtained as shown, with the burner eccentric to the holes in the fire-box, as this setting of the burners was found to conduce to economy in steam at the ring blower jets and to utilise the steam to its utmost for air induction. It will be noticed that the ring blower attached to the burner is arranged eccentrically to the nozzle; that the brick arch usually provided on coal-burning engines has been retained to obviate the too direct passage of the products of combustion to the tubes and to ensure a thorough combination; also that the fire-door is provided with a deflector as shown, to direct downwards into the centre of the fire any air admitted at the fire-door, this practice being common to coal- and oil-burning engines. It will thus be seen that all the features necessary to the successful burning of solid fuel are retained.

With regard to the composition of the base or hearth

over which the liquid fuel is to be burnt, if coal and liquid fuel are to be burnt in conjunction, a thin layer of slow-burning coal will be found to be most efficient, with the damper of the ash-pan opened sufficiently to give an easy draught and ensure a bright fire. In this direction a variable blast pipe has been found of considerable benefit on the engines of the Great Eastern Railway, when burning liquid fuel in conjunction with coal, the opening of the exhaust orifice being enlarged by 30 per cent. in area, whilst if a return to coal alone is desirable, and a sharper blast required, a hinged cap provided at the top of the blast pipe, and having a reduced area, can be lowered over the outlet, and the velocity of the escaping steam increased.

When liquid fuel is used alone, the procedure of working is somewhat as follows: steam is first raised in the boiler by a wood and coal fire kindled in the ordinary manner, and when from 30 to 40 lbs. pressure shows on the gauge the fire is levelled over and covered with a layer of broken fire-brick of not more than 3-inch cubes. This covering is spread so that it is thinnest about the centre of the fire-box, and well packed round the sides and corners. A few pieces of waste or wood are thrown in to cause flame, and the liquid-fuel spray is started by opening the steam supply to the central cones of the burners and admitting the liquid fuel through the regulating valves. At first the fire will appear dull with probably considerable smoke; but soon after adjusting to approximately the requirements of the moment, the secondary steam supply is opened to admit sufficient steam to the jets of the ring blowers to induce the necessary air for complete combustion and to atomise and distribute the spray as already described, the fire burns with whitened intensity and all smoke disappears.

The position of the burners relative to the grate will appreciably affect the noise of working. If too high, the introduction of the oil spray and air causes a series of minute explosions among the products of combustion from the fire below, and an intolerable hum ensues, whereas if the oil fire is maintained along the plane of the coal fire, the action is all but noiseless.

On the Great Eastern Railway coal tar and its by-products have been used as well as petroleum residuals.

The means of storage and supply must necessarily be considerable, and the arrangements at Stratford for this purpose are the most complete in Great Britain, and consist of a series of underground tanks, having an aggregate of 50,000 gallons capacity, arranged to receive the oil by gravity from the tank waggons. A small steam-driven rotary pump delivers the oil fuel into six large cylindrical reservoirs, elevated 20 feet above rail level, and having a total capacity of 42,000 gallons. Outlet pipes controlled by valves operated from a gallery above conduct the oil from these high-level reservoirs to filling posts or arms similar to ordinary locomotive water cranes, but somewhat smaller, for filling the tanks of the engines coming to the depôt for fuel. The whole plant is worked by four men, one of whom is exclusively employed on the night duty of filling the engines, whilst the other three, a chargeman and two assistants, are engaged during the day in pumping the oil, emptying the tank waggons, and filling any engines arriving for day service.

A main-line express engine can take 600 gallons of liquid fuel in a period of from four to five minutes, and as the whole installation is lighted by electricity, with portable lamps for the filling arms, it can readily be understood that the facilities of distribution are far greater with liquid fuel than with any system of coaling, no matter how mechanical. At the country depôts where liquid fuel is used, it is stored in underground reservoirs and delivered to the locomotives by air pressure. The air is pumped into the reservoir by the brake pump of the locomotive, the driver and fireman manipulating the gear precisely as they would if renewing the water supply. The liquid-fuel tanks of the locomotive have a fine gauze strainer protected by a perforated cylinder of thin metal; this ensures a thorough clearing and filtration of the fuel prior to its entry into the tanks, pipes, and burners, and further acts as a safeguard against any danger from naked lights, should light oils or vapour happen to be present. This is a precaution more necessary when crude oil is used than when residuals are employed, and on the Great Eastern Railway, where the latter are usually the fuel, the gauze is employed more for filtration purposes than for the sake of safety.

Engines similar to that illustrated have frequently made the through run from London to Cromer, 138 miles, in 175 minutes, with one stop of 4 minutes 7 miles from the latter town, on a consumption of 190 gallons of tar oil (specific gravity 1·1) equivalent to 14·4 lbs. of oil fuel per

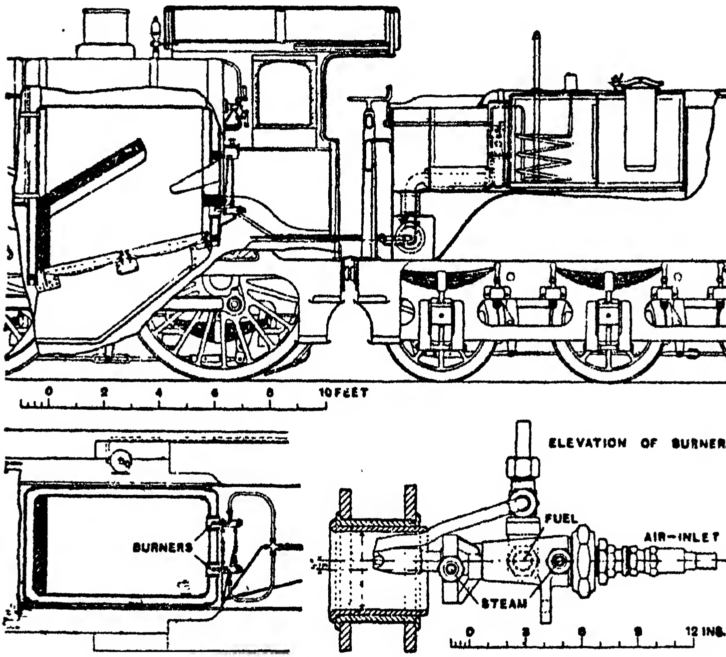


FIG. 85.—General arrangement of liquid-fuel burning apparatus (Holden) on four-coupled express engine. Great Eastern Railway.

train mile; to this must be added 6 cwts. of coal used to light the fire and raise steam, equal to 5 lbs per mile, or a total of 19·4 lbs. per mile. On these journeys from 5 to 6 cwts. of broken fire-brick (old brick arches) are spread on the grate.

The system used on the Great Eastern Railway has been largely adopted in foreign countries: including the 32

engines fitted for operating the Arlberg tunnel on the Austrian State Railways, and a number of engines on the Western Railway of France, the Paris, Lyons and Mediterranean and the Paris and Orleans Companies. Also in the Far East numerous locomotives and stationary boilers have been fitted on this system. The Holden burner is also largely used on the Roumanian State Railways.

One of the consequences of the 1912 and subsequent coal strikes has been a further development of oil as fuel on the British Railways. But, in spite of its many advantages, it has not, up to the present, appreciably taken the place of coal, owing partly to the uncertainty of getting supplies of oil in sufficient quantities at a low enough price, and partly to the difficulty and cost of fitting the necessary apparatus.

On the Caledonian Railway,[1] profiting by the experience gained by the Great Eastern Railway, two engines were fitted in 1912 with oil-burning injectors. The oil is stored in a cylindrical tank holding 520 gallons, placed on the tender, and flows by gravity to the two burners, spaced about 18 inches apart, which atomise it by a supply of steam in the form of a fine spray in the fire-box. A series of steam jets from a ring on the burners (*vide* figs. 15–17) act on the spray at an angle, so that it is broken up before striking the fire-brick wall W (*vide* fig. 86), which is built up to protect the copper plates, as an addition to the customary fire-brick arch A. Two openings for the burners are made through the water space of the fire-box and lined with bushes F, 4-inch diameter inside. These are placed about 8 inches above the fire-bars, on which is placed a thin layer of coal or wood fire to ignite the spray. Regulating valves S, L, control the supply of oil and steam, and ensure perfect combustion. The engine can still be fired with coal, if desired, without in any way interfering with the liquid-fuel apparatus, which is one of the great advantages of the Holden system of oil-burning, and which, by the way, has been recently fitted to No. 10 express locomotive of the Midland Great Western Railway of Ireland. Similar apparatus has also—some years back—been fitted to No. 51 engine, on the Northern Counties

[1] *The Locomotive.*

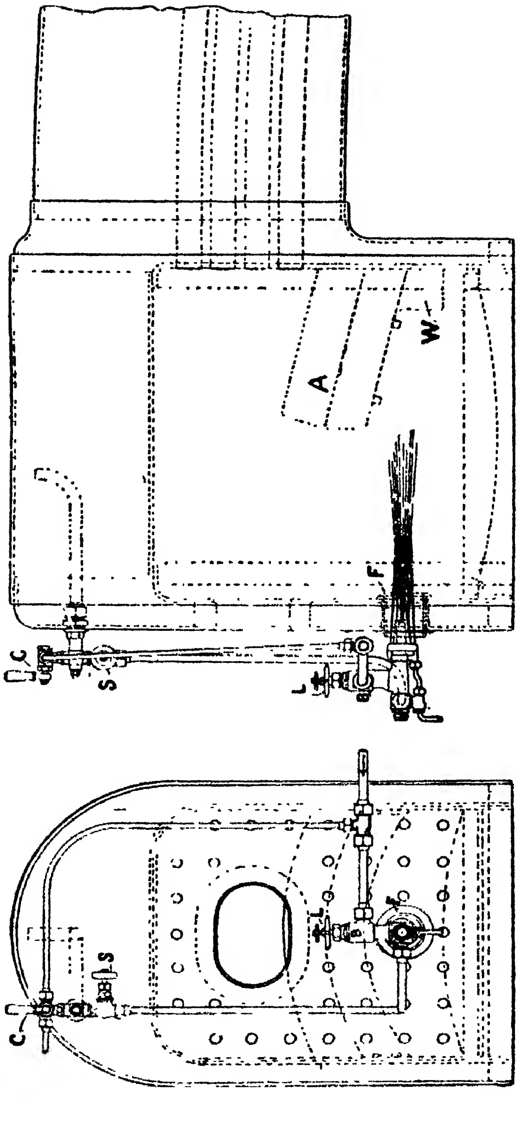


FIG. 86.—Locomotive fitted for oil- or coal-burning on the Holden system.

and on one of the "305" class, 4—4—0, on the Great Southern and Western Railways. The Caledonian and the Midland Railways have also adopted oil-burning apparatus, No. 779, four-coupled bogie express engine of the latter being fitted up on the Holden system. The smallest locomotive fitted up with a Holden burner—one of several for use in Mexico—has cylinders only 6½-inch diameter, carries 350 gallons of water plus 150 gallons of oil, and weighs complete in working order 11½ tons.

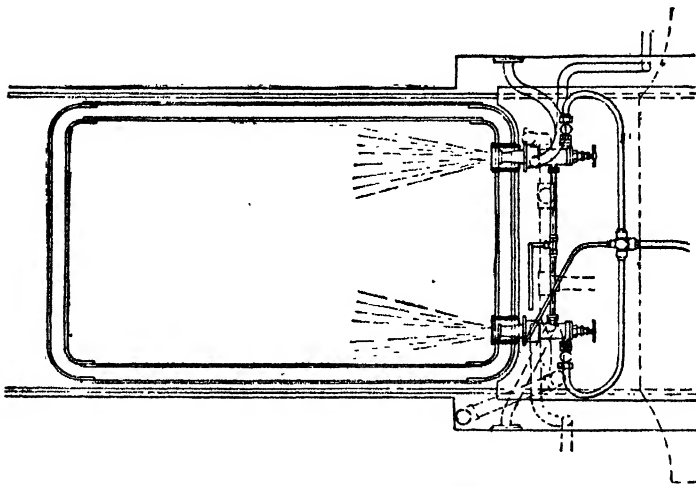


FIG. 87.—Sectional plan of locomotive fire-box fitted with a pair of Kermode steam-jet burners.

Another pioneer in this line of work was Professor Urquhart, the late engineer of the Grazi-Tsaritsin Railway, in S.E. Russia. In a paper he read on the subject of liquid fuel before the Institute of Mechanical Engineers, in 1899, he stated that he had under his superintendence 143 locomotives fired with petroleum refuse, besides 50 stationary boilers and some furnaces. The waste residuals used, there known as astatki and mazout, had a calorific value of 19,832 thermal units taken on the higher scale; therefore about 1200 thermal units should be deducted for the latent heat of the steam produced in combustion. The calorific

value, as fuel, was therefore about 18,600 thermal units per pound and the evaporative power 19½ lbs. of water from and at 212° per pound of fuel. The highest actual evaporation obtained was 14 lbs. per pound of oil, at 125 lbs. per square inch, from 60°. This would be equivalent to 16·8 lbs. from and at 212°; but from this, of course, must be debited from 0·8 to 1 lb. for the burner.

Again, if the steam were not dry, then the real would be less than the apparent evaporation. It should be noted further that, in a locomotive with iron tubes, the evaporation is given as 12½ lbs. per pound of oil, and this is stated to be "the ordinary practice of locomotives." Urquhart also said that at a printing works at Moscow, with a stationary boiler of locomotive type, an evaporation equal to 13½ lbs. per pound of oil had been obtained.

In figs. 88 and 89 are illustrated the necessary modifications of ordinary passenger and freight locomotives to burn oil on the Urquhart system.

A modified form of the Urquhart burner is also employed on the Madura street tramways in the Dutch Indies. The oil is supplied by the Dordtsche Petroleum Company, and is of a somewhat viscid character. In order to warm up the residue and so increase its fluidity, a pipe is coiled around the sieve in the reservoir, which pipe can be supplied with steam from the main boiler by turning a cock from the supplementary boiler by means of a pipe and a three-way tap. The water condensed in the coiled pipe can be blown off on to the wheel rims in order to reduce the amount of wear. The actual burner is placed below the iron fire-box, and is bolted on to the ash-box. The oil-fuel pipe leads into the side of the burner, and the steam-pipe into the top. The steam may be either obtained from the main boiler or from a supplementary boiler.

For simplifying the service, an equilibrium valve set at 5 to 6 atmospheres pressure, and controlled by a pressure gauge, is fitted to the pipe conveying steam to the burner. Between the boiler and this valve is a strainer (readily accessible for cleaning), which retains all solid matter (fragments of wood, stone, etc.) carried by the steam. The supply of fuel is regulated by a hand-wheel mounted at a convenient height on the boiler and controlling the feed cock.

The results furnished by these locomotives were very favourable. The charging of the reservoir with 66 gallons

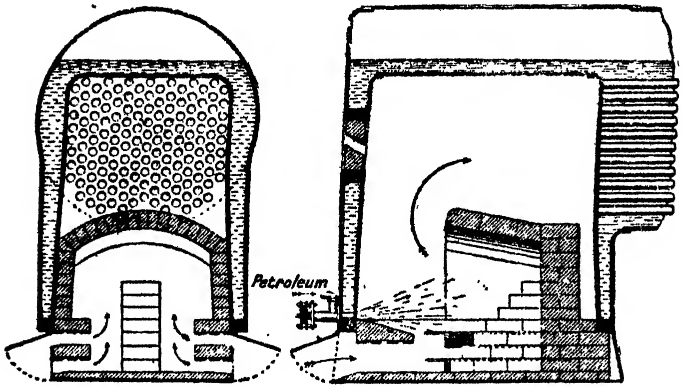


FIG. 88.—Arrangement of express locomotive fire-box for oil-burning on the Urquhart system.

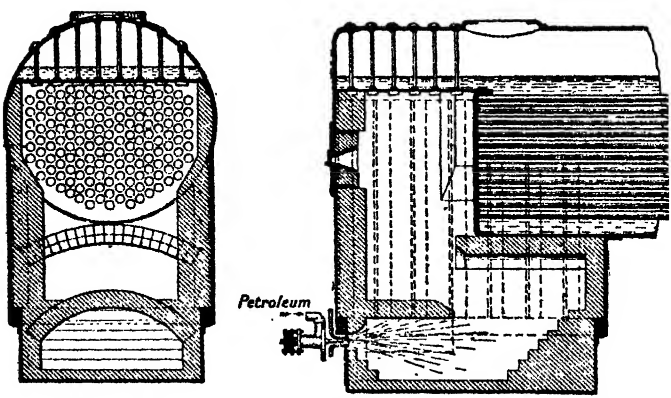


FIG. 89.—Arrangement of freight locomotive fire-box (Urquhart-Verderbur system).

of residuals occupied 15 minutes, the fuel being warmed up by steam from a supplementary boiler to 45° C.

According to Professor Urquhart, the cost of transforming a locomotive burning coal to one capable of burning oil on

his system amounts to £40; this is the sum which he himself expended on the conversion of a six-wheeled engine on the Grazi-Tsaritsin Railway in Russia; but this was more than twenty years ago, and is no criterion of the cost there now! In an eight-wheeled engine, in which

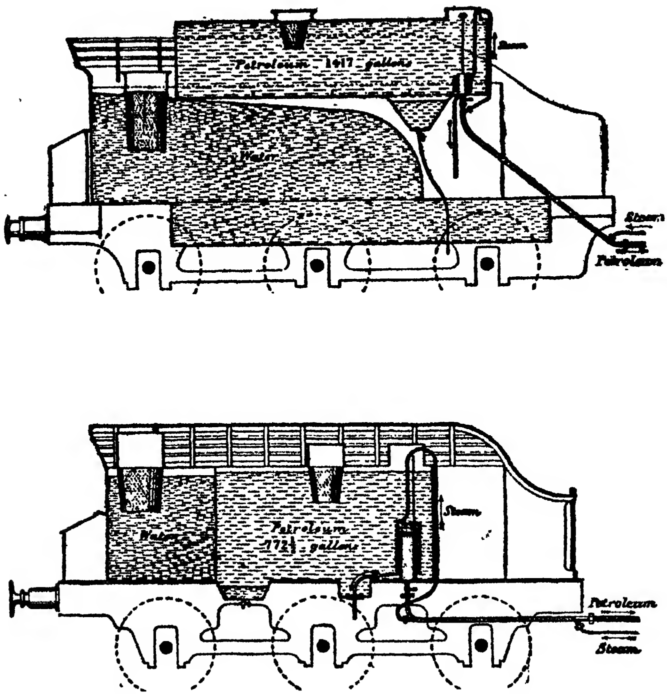


FIG. 90.—Tenders used for oil-burning locomotives (Urquhart system).

the coal space had to be increased, the outlay amounted to £77.

In the six-wheeled engines the average cost of fuel per engine mile was reduced from 7·64d. for coal to 4·43d., or 42 per cent.; in eight-wheeled engines the reduction was from 11·02d. to 5·84d., or a saving of 47 per cent. In the former type of engine the equivalent of 100 tons of

coal was 55 tons of oil, while in the eight-wheeled engine 50 tons of oil displaced 100 tons of coal.

In order to satisfy themselves that fuel oil was as well adapted as coal for firing locomotives having to traverse a mountainous country, the Japanese Government ordered tests to be made on its Shin-Yetsu line. The results of this test were considered as satisfactory as those made on roads traversing a comparatively level country. The fuel oil used came from the district known as Northern Echigo. The Japanese Government are now also using oil fuel on the Tokaido line, as a portion of this line runs through the Hakone passes, where there are many tunnels, which cause the heavy smoke and gases from the coal burned in the engines to accumulate unpleasantly.

The Ohugwai Shogyo and other lines are having their locomotives converted from coal to oil firing.

Turning now to American practice, we find quite a number of examples. Of these, the W. N. Best is perhaps the most used; this is shown in fig. 91, arranged in a 6-wheeled engine, and in fig. 92 for a heavy 8-wheeled engine, in which the depth of the ash-pan permits of the spray being injected beneath the fire-box block ring. In this engine there is a very considerable setting of fire-brick lining used; so much so, indeed, that the sides of the fire-box are not surrounded by water, the endeavour being to obtain a very high temperature of the combustion chamber.

In figs. 91 and 92 are illustrated designs of locomotive fire-boxes employed on the Los Angeles and Tehuantepec Railways; in both of these the oil is injected by a steam-jet burner arranged below the fire-box ring, the latter also resembling the Verderbur furnace (Hungarian State Railways) in that the lower half of the fire-box is not water-jacketed, but fitted with an extra depth and thickness of brick lining which, with the heavy arch used, entails considerable expense in renewals, according to the statement made by Mr Louis Greaven, the late locomotive superintendent of the Mexican State Railways, who has tried several designs of furnace setting, some having an inverted arch floor and others flat. The arrangements, also, for the supply of air have been varied to a considerable

extent, the best results being obtained by a series of air flues extending up through the brick lining at the forward end and thence into the furnace by openings in the arch.

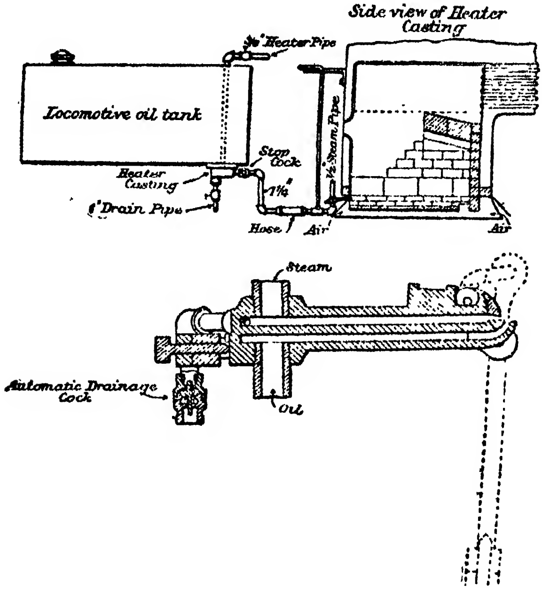


FIG. 91.—Best's oil fuel apparatus.

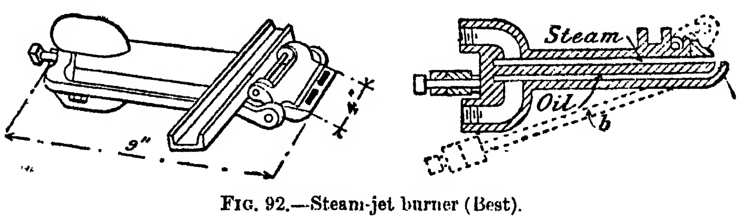


FIG. 92.—Steam-jet burner (Best).

On each of these railways the W. N. Best burner, in which the oil channel is below the steam atomiser instead of above it, is used, and is now one of the systems being tried on the Paris, Lyons and Mediterranean Railway,

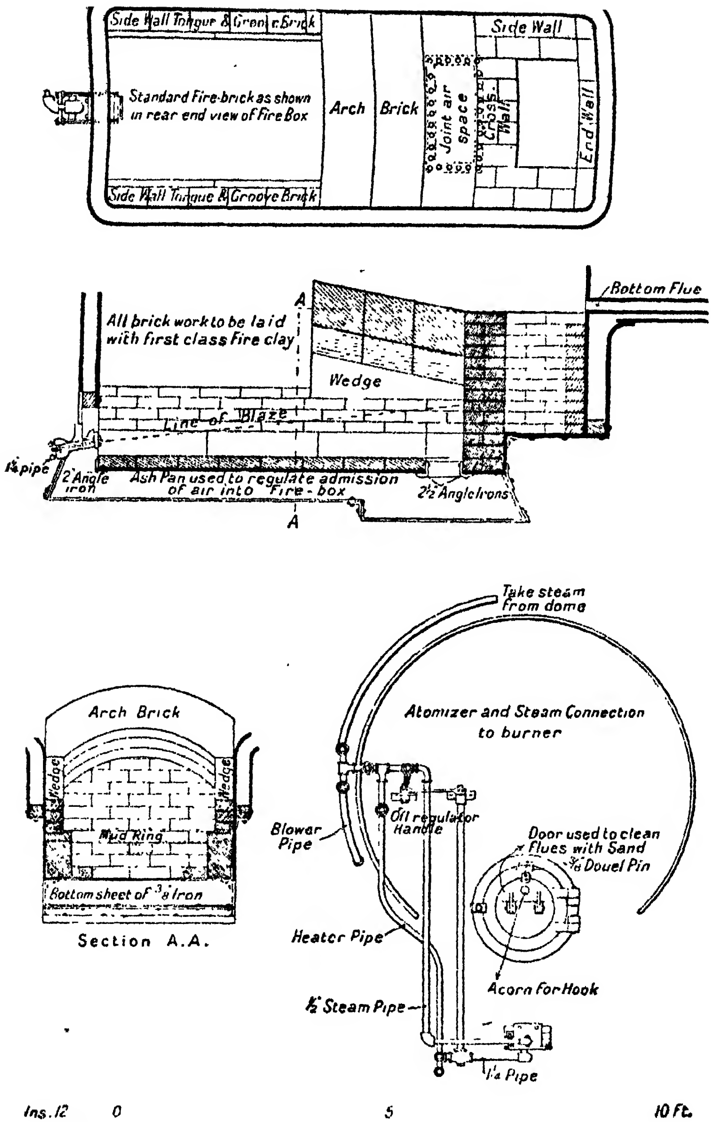


FIG. 93.—Locomotive fire-box arranged for oil-burning on Best's system.

also referred to in Chapter VI. The nose-piece of the atomiser is held in place by a hinged bridle *b* (*vide* fig. 92),

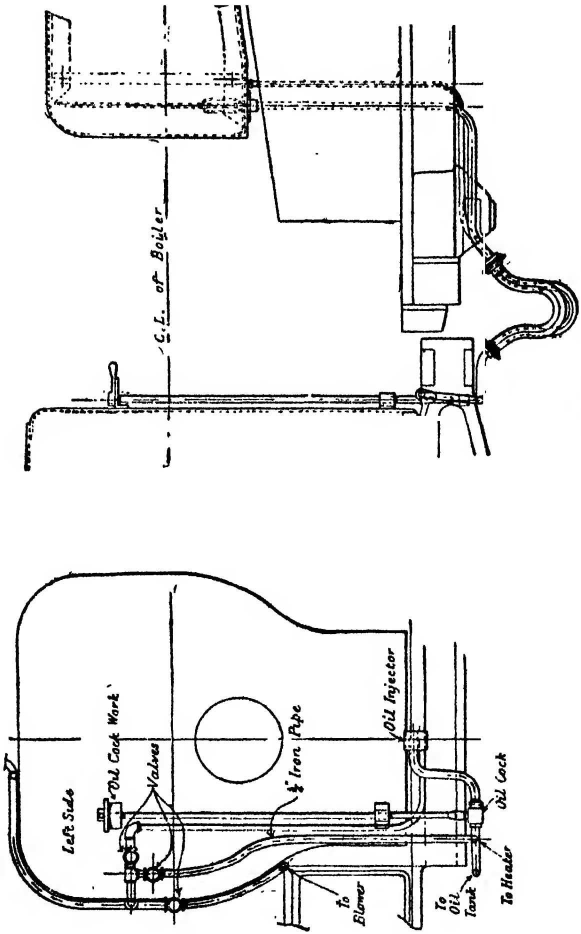


FIG. 94.—Arrangement of oil and steam connections between engine and tender (Greaven).

so that it can be quickly removed if the steam passages become stopped. There is also an automatic release valve for draining the steam pipes and passages when the burner

is not in use. A spiral spring acts to raise this drainage valve, which remains open until steam is turned on in the burner, when it closes automatically, so preventing water from reaching the refractory walls and arch and injuring them.

Among the locomotives at the Ghent (1913) International Exhibition there was a 0–6–0+0–6–0 Garratt locomotive, built by the Société St Léonard, for the Congo. The boiler of this engine—which is oil-fired—is suspended between two six-wheeled bogies, over one of which is

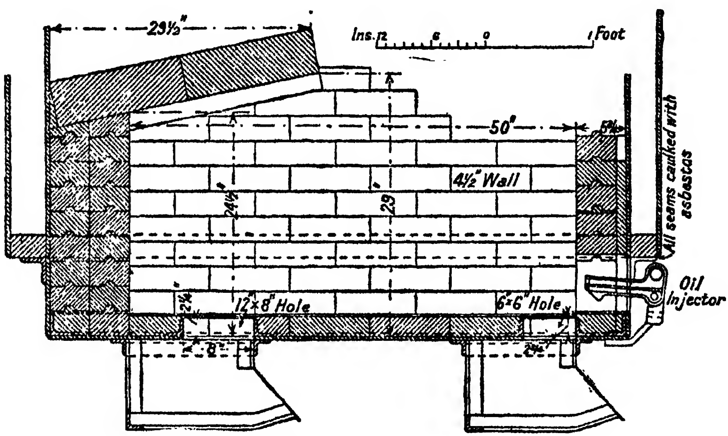


FIG. 95.—Fire-box of oil-fuel locomotive (Baldwin).

mounted the water tank and over the other the oil tank. The Garratt burner is described in Chapter VI., fig. 25, and as used on the Lima Railways, Peru, is quite easily detachable, so that, in the event of the supplies of oil failing, coal can be at once used.

In the United States oil-firing has made considerable progress in recent years, and in this connection is illustrated the fire-box of a small "Mogul" oil-fired engine, fig. 95. In this, which is 50 inches long by 25 inches wide inside the brickwork, the ash-pan, or what would be the ash-pan in a coal-burning locomotive, is lined to a height of about 29 inches with a 4½-inch brick wall, except at the tube plate towards which the burner is directed. The tube

plate is fitted to a 9-inch fire-brick wall surmounted by a brick arch, and the ash-pan with a layer of 2¾-inch *fire-bricks and two openings for air, one 12 inches by 8 inches at the front and the other 6 inches square just* below the burner, which is placed below the mud-ring at the back of the fire-box. The burner, which is of the drooling type, is of extremely simple construction, and consists of two chambers one above the other, the oil coming through the upper chamber and the steam through the lower; these terminate in two wide horizontal slots; through the upper slot the oil flows in a film, which is turned into a spray by the blast of steam through the lower slot (*vide* p. 73). The Baldwin Locomotive Works' rule is to make the slot 1 inch wide for each 100 square inches of cylinder area.

On the Southern Pacific system, on which over 1000 locomotives are of the oil-burning type, the oil is carried in tanks built to fit the coal space in the tender. Additional flat tanks when required are placed over the coal space or back of it. Gravity supply is depended upon through flexible pipes to the locomotive. Each system of oil tanks on the tender is provided with a gauge board or scale from which the fuel records are kept.

The burner used is of the flat-jet type, consisting of a casting divided longitudinally by a partition over which the oil flows as it is admitted to the upper cavity. The lower cavity receives the steam for the jet which strikes the oil flowing over the partition, spraying it into the furnace. The aim is to atomise completely the oil near the burner tip in order that it may be immediately vaporised.

The steam for atomising is obtained from the dome, and is available at full boiler pressure of 200 lbs. through a suitable regulating valve. Compressed air, also, has been used experimentally, and for some time in combination with a form of burner that delivered air inductively to the burner itself. Other than by a localisation of heat at the point of the burner, no benefit could be found by tests with air mingled with the steam in this way. Atomisation with compressed air is undoubtedly of value under certain conditions, but is liable to produce locally in the furnace a more intense heat than is desirable. With the steam jet the oil

is sprayed and broken up so as to allow the air admitted through proper dampers to mix and the oil to be *consumed completely without damage to the sheets.* Tests on Southern Pacific locomotives show that temperatures ranging from 2500° to 2750° F. are obtained, the latter being the highest observed.

The method of fitting a locomotive fire-box for oil-burning is shown in fig. 96. Fire-bricks, the most refractory obtainable, are placed at the lower side of the fire-box plates to prevent impinging of the oil blast against the sheets. No more bricks than are necessary for the purpose are used. The most *refractory bricks melt out in a comparatively short time—not from an intense degree of heat,* but from the fluxing agents introduced with the oil, especially salt or other alkalies, with which California petroleums are associated.

According to the experience of this Company, fire-box repairs to oil-burning locomotives do not exceed those of coal-burning engines; but a greater depth of fire-box is more essential for economic oil-burning than for coal. If combustion is not approaching completion when the gases enter the flues, the vapours in process of combustion fall in temperature below that required for oxidation of the carbon, which is precipitated as soot or black smoke. While this is a common phenomenon of smoke production with any fuel, it is more in evidence with oil than with solid fuel, where there is nothing to burn but volatile combustible. Lack of oxygen is generally supposed to be the cause of smoke, but lack of proper temperature required for chemical combination is as often, if not more often, the cause. The lack of sufficient fire-box volume is the common cause of smoke in oil-burning locomotives when the greater demands are made on the boiler for rapid evaporation. The deposit of soot upon locomotive flues is a common difficulty and calls for the regular operation in service of sanding the flues. Soot is a poor conductor of heat, and the steaming quality of a locomotive rapidly falls off when flues become lined with soot. The operation of sanding consists in dropping a reverse lever, if possible while the engine is running, pulling the throttle wide open, while the fireman puts a few cupfuls of sand through the opening in the fire-

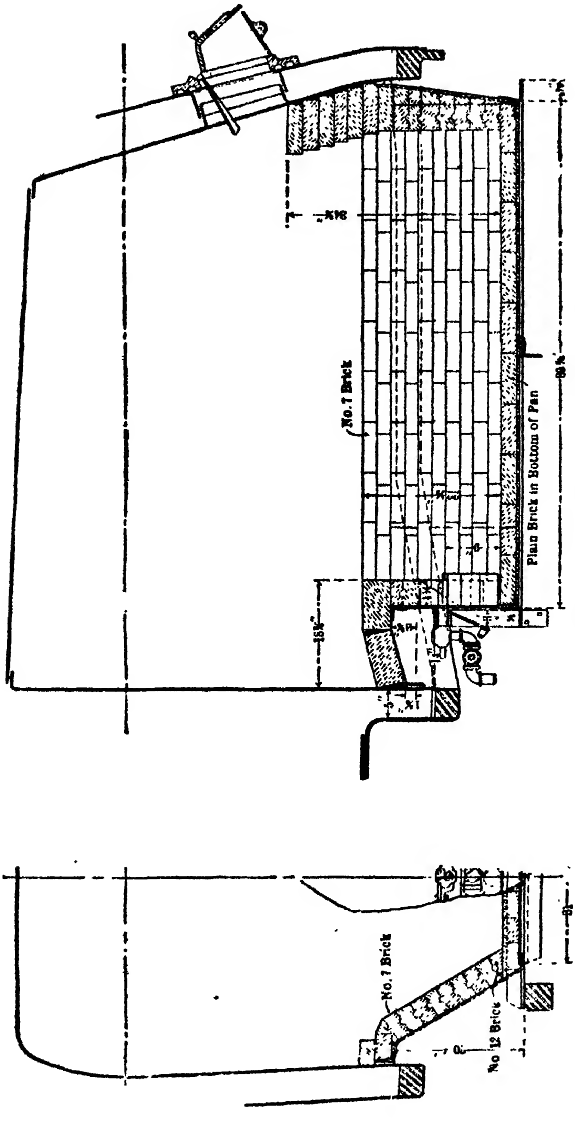


FIG. 96.—Southern Pacific locomotive fitted for oil-burning.

door, the draught carrying the sand through the flues and ridding them of soot, the operation being repeated if necessary. A supply of sand is carried on the foot-plate for this purpose.

In oil-burning the factor of grate surface disappears. The grates are bricked over, and air admission regulated through openings and proper dampers. There is no function corresponding to grate surface such as used in connection with coal-burning. Only the item of heating surface remains on which to base comparisons.

The rate of combustion in a locomotive, like other functions, depends on the service and size of the machine. While the principles of combustion do not vary in locomotive boilers from those in stationary service, there is a wide variation in the rate of steam production, independent of the kind of fuel used. With the modern locomotive in main-line service the demand for steam at full pressure per unit of heating surface far exceeds, in point of time, the product of a stationary boiler. The demand on the locomotive is intermittent and conditions vary from an enormous rate of steam production, when working at a rate of maximum effort, to one of comparative rest. A large number of locomotive tests have been made by the Southern Pacific Railroad, covering the use of fuel oil, as well as in comparison with coal. The accompanying table shows evaporative results on most recent tests, covering about the heaviest oil-firing which we have, crossing the Sierra Nevadas.

Class of engine	10-wheel
Service	Passenger
Date of test	May 21 and 26, 1908
Number of single trips in test	2
Total time of test	17 hours 39 mins.
Actual running time	13 hours 55 mins.
Miles run	315
Average steam pressure (gauge), lbs.	196·0
Smoke box temperature, °F.	797
Total gals. water evaporated	44,147
Total lbs. water evaporated	367,642
Total gals. oil burned	3951·6
Total lbs. oil burned	31,613
Equivalent evaporation, lbs. water per lb. oil	14·14
Lbs. water evaporated per square foot heating surface per hour	8·698
Lbs. oil burned per square foot heating surface per hour	0·748

Number of cars in train	7
Weight of train, tons	342
Gross ton mileage	107,730
Gals. water evaporated per 1000 ton miles	409·79
Lbs. water evaporated per 1000 ton miles	3413
Gals. fuel oil burned per 1000 ton miles	34·90
Lbs. fuel oil burned per 1000 ton miles	279·20
Boiler efficiency, per cent.	73·84
Maximum i.h.p.	1719
Mean i.h.p.	1368
Engine number	231
Size of cylinders, ins.	22 × 28
Diameter of drivers, ins.	63
Total weight of locomotive, lbs.	203,300
Weight on drivers, lbs.	160,000
Weight of tender, lbs.	138,070
Total heating surface, square feet	2994

Note.—Train weights are the average for the distance hauled and are exclusive of engine and tender. Tests made under ordinary service conditions. Engines unaided. In "water evaporated and oil burned per square foot heating surface per hour," the figures are for actual running time; the allowance of 15 gals. of oil and its equivalent in water is made per hour while standing. In "gals. and lbs. oil per 1000 ton miles" a deduction is made of 15 gals. per hour while standing and 3·5 per cent. of oil for evaporating steam for atomising oil. Quantity of oil burned corrected to normal temperature of 70° F. All measuring instruments calibrated. Analysis of fuel: Kern River oil; gravity, 15·8° Beaumé; flash point, 230° F.; fire point, 278° F.; commercial weight, 8 lbs. per gal., U.S.A.

In fig. 97 is shown another example of oil-firing practice followed by the Southern Pacific; here, as in fig. 96, the burner is placed in the front of the fire-box and the spray directed backwards. A sort of fire-brick wall is made, extending below the fire-box proper, with walls 4½ inches thick, except at the back towards which the oil jet is directed. The back wall is 10½ inches thick. With this arrangement no brick arch is used, as the natural sweep of the gases from the front of the box to the back, and then forward again into the flues, fills the fire-box with flame and so protects the tube ends. In a fire-box 85½ inches long by 30 inches wide inside the fire-brick, air is supplied through an opening 18 inches by 10 inches near the back of the box. The Southern Pacific Railway arrange the pipe supplying oil to the burner through a steam-jacket to cause it to flow more freely. In the Baldwin Locomotive Works' burner a certain amount of preheating is secured by the oil traversing the length of the burner in proximity to the steam.

For steam raising, whether on land or afloat, and especially on locomotives, oil-burning is now so well established as to be able to hold its own with coal wherever the cost of oil fuel—compared weight for weight—does not exceed double that of coal, including delivery to the bunkers or tanks of the boiler yard, ship's hold, or engine tender. Its importance to British railways therefore, when considered simply from the point of view of economy, would not seem to be so very great, so long as strictly considered for its

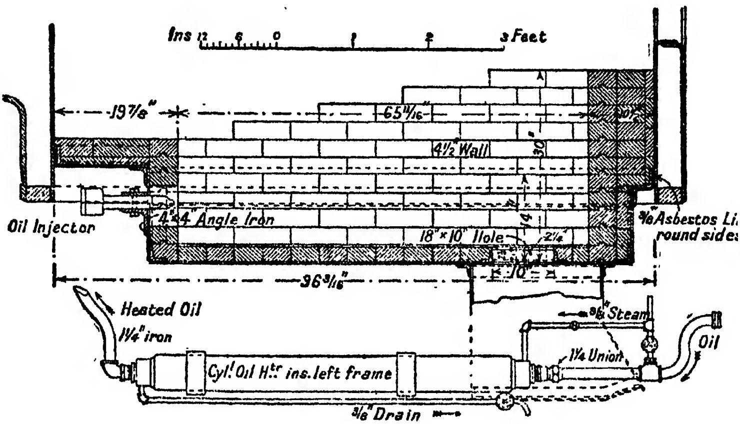


FIG. 97.—Fire-box of oil-fuel locomotive (Southern Pacific Railway).

relative heating value. But for general industrial purposes there are often conditions that should not be overlooked when comparing liquid with solid fuel which materially change the economical aspect, the most important of these —whether considered for steam raising or for furnace heating—being the relative cost of transport, which, owing to the difference in heating value of the two fuels, favours the use of oil when either fuel has to be conveyed any considerable distance.

For instance, in the United States we find oil fuel used for power purposes on an extensive scale, mostly over a comparatively small area, in Texas, parts of Pennsylvania and California; from the fields of the last-named State the

Great Northern Railway have now decided to draw their fuel supplies for feeding the hundred locomotives or so used westwards of Leavensworth. For this purpose the oil must be first shipped to Seattle, then tanked and pumped through a distributing pipe to smaller tanks at intervals along the line. Of the other most important instances of the use of oil fuel on railways in the States may be mentioned that of the Southern Pacific. According to Mr Louis Greaven, late locomotive superintendent of the National Railroad of Mexico, the cost of fuel per train mile with fuel oil brought from Texas at 29s. per ton, and coal at 32s. per ton, was slightly in favour of oil, viz., 5d. as against 7d. for coal. And, again, on the railways of Peru, where fuel oil is considerably used, the relative cost, according to Mr H. W. Garratt, was as 8 to 13, thus showing an advantage in favour of oil approaching nearly 40 per cent., when the cost of oil fuel was 45s. per ton as against 35s. for coal. The comparison is, of course, more pronounced on the State Railways of Southern Russia and Central Asia, where astatki and mazout are almost exclusively used, the former drawing most of its supplies from the Caspian fields and the latter from Ferghana.

The following is an abstract from a report on an elaborate series of tests carried out in 1912 by W. F. M. Goss, D.Eng., on a Jacobs-Shupert locomotive boiler in comparison with an ordinary radial-stay boiler with oil and coal fuel.

"The general dimensions of the boiler tested were as follows:—

	Jacobs-Shupert.	Radial-stay.
Type of boiler	Ext'd waggon top	Ext'd waggon top
Diameter of shell	70 ins.	70 ins.
Number of $2\frac{1}{4}$-in. tubes	290	290
Length of tubes	18 ft. 2 ins.	18 ft. 2 ins.
Length of fire-box	9 ft. $1\frac{5}{8}$ ins.	9 ft. $1\frac{1}{16}$ ins.
Width of fire-box	6 ft. $4\frac{3}{8}$ ins.	6 ft. $4\frac{1}{4}$ ins.
Total heating surface	3008·4	2989·3

"The percentage of the total heat absorbed by the boiler, which is taken up by the fire-box, varies with the rate of

power at which the boiler is worked. It is affected also by the character of the fuel used.

"When oil fuel was fired at the rate of 2200 lbs. an hour:

"(*a*) The Jacobs-Shupert boiler evaporated 40,000 lbs. of water per hour. Of this amount, 16,000 lbs. were evaporated by the fire-box and 24,000 lbs. by the tubes.

"(*b*) The whole boiler developed 1200 h.p., of which amount nearly 500 h.p. was developed by the fire-box.

"(*c*) The average rate of evaporation per foot of heating surface per hour for the whole boiler was 9·78 lbs.

"(*d*) The average rate of evaporation per foot of heating surface per hour for the fire-box was 49·59 lbs., and for the tubes 6·47 lbs.

"(*e*) The ratio of heat absorbed per foot of heating surface by the fire-box to that absorbed per foot of tube heating surface was as 7·6 to 1.

"When a long-flamed bituminous (Dundon) coal was fired at the rate of 4340 lbs. per hour:

"(*a*) The Jacobs-Shupert boiler evaporated 35,405 lbs. of water per hour, of which amount 11,982 lbs. were evaporated by the fire-box and 23,423 lbs. by the tubes.

"(*b*) The whole boiler developed 1026 h.p., of which amount 304 h.p. were developed by the fire-box.

"(*c*) The average rate of evaporation per foot of heating surface per hour for the whole boiler was 11·77 lbs.

"(*d*) The average rate of evaporation per foot of fire-box heating surface was 51·92, and for the tube heating surface 8·43.

"(*e*) The ratio of heat absorbed per foot of fire-box heating surface to that absorbed per foot of tube heating surface was as 6·15 to 1.

"Each pound of oil burned resulted in the evaporation of from 15 to 13·2 lbs. of water, the amount diminishing as the rate of power is increased. The thermal efficiency of the Jacobs-Shupert boiler under low rates of power may exceed 80 per cent., and even under high rates of power it is above 70 per cent. It can be shown that when the boiler is made to evaporate 20,000 lbs. of water an hour, it will generate 14·14 lbs. of steam for each pound of oil burned; also at the same rate of power it will generate 8·3 lbs. of steam for each pound of

Dundon coal burned, so that a comparison of the results makes 1 lb. of oil in locomotive service equal to 1·7 lb. of high-grade bituminous coal."

As before pointed out, the pressure-jet oil-burning system is better adapted to a battery of boilers than to a single boiler, and it would seem that its application on a locomotive (owing to the limited space at disposal for the necessary pump, heaters, and filtering apparatus) must demand some unusual compensating advantage, whether due to the more equable diffusion of the flame, greater facility for raising steam from all cold, or to the increased economy in fuel consumption. However, a design for a pressure-jet oil-burning apparatus has been got out by the Schutte-Körting Co. for a locomotive in which the complete plant necessary for firing on the pressure-oil system is carried on the footplate. In the illustration, fig. 98, it will be seen that a series of spraying nozzles N is used, very similar in form to the nipple of a blow-flame burner, the main difference, apart from size, consisting in the heating of the oil under pressure, and to an incandescent surface for the fuel to impinge against. In this case the combustion chamber is surrounded on each side and bottom with fire-brick setting, excepting for the necessary openings for the admission of spray and air at the rear end and for air at the front end, the supply to each of which is controllable by dampers. Oil from the tender is supplied to the pipe as indicated, and after first passing through the suction heater SH, and either one of the duplicate suction filters SF, it is forced by the oil pump SP to the pressure heater PH, and thence to one of the two pressure filters PF, whence the oil is conducted straight away to the burner nozzle N. For starting up from cold, an auxiliary supply of gasoline can be conveniently used until a sufficient head of steam is raised to operate the pump, which meanwhile is arranged to be actuated by a hand lever.

This chapter dealing with oil fuel in its application to the special requirements of railway work may opportunely conclude with a few salient remarks on the management of locomotives running on oil fuel:—Care must be exercised, as in coal engines, to raise the pressure slowly. In oil-fired engines firing must never be forced on any account, the

attending evils being the filling and choking of tubes with soot, burning of the inner shell, of the rivet heads, and causing the boiler to leak. In case the pressure of steam falls it must be gradually restored to the working limit by easy stages of increase. On the run, if the engine

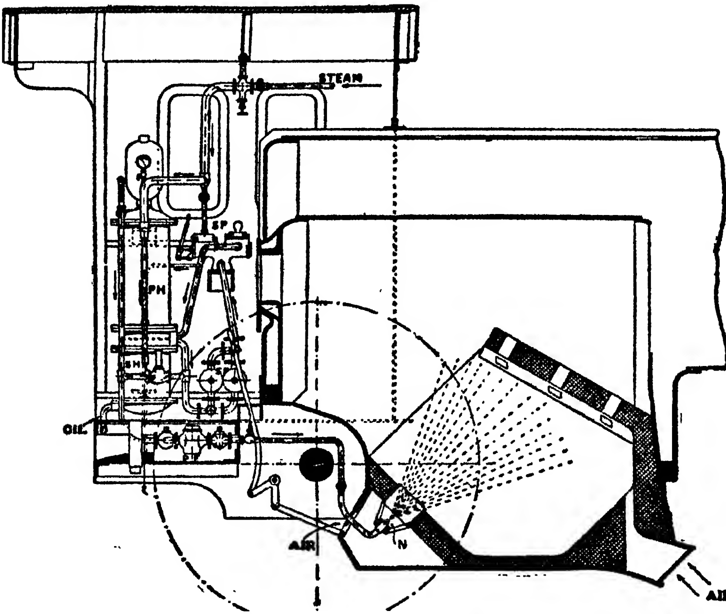


FIG. 98.—Locomotive fitted with Schutte-Körting oil-burning apparatus to fire on the pressure-jet system.

tends to soot up, the sand blast should be used, care being taken to direct the jet above the brick arch. Sanding must be repeated so long as black smoke is seen to issue from the funnel, since this soot tends to lower the head of steam by filling the tubes. An oil fire must not be put out entirely till the engine is placed in the shed at the end of the journey. In waiting at stations the fire may be reduced if the injector is not working. To ensure perfect combustion

in locomotives using oil fuel, an accurate combination of oil and steam is necessary. Heating the oil in the tanks is desirable, but when so doing the fireman must open the heater at intervals only, and send steam in the tank to warm it sufficiently. It is bad practice to steam the heater a little continuously; heating the oil ought to be done while standing as much as possible. Opening the heater valve too often will accelerate the condensation of steam in the oil tank, and eventually will prevent a regular flow of oil. At the end of a trip the fireman must first shut off the feed valves and allow the escape of the oil in pipes to burner where it is to be consumed; the dampers and regulating valves must next be closed. *It is important that as soon as the feed is shut off the dampers be closed down, so as to prevent the admission of cold air to the fire-box and tubes.*

Great care must be exercised in approaching a manhole or vent in the oil tank, on account of the danger from explosive gases that may have been generated at a low temperature. To find out the amount of oil in tank the fireman must use the rod provided for that purpose, carrying it, if at night-time, to the light to ascertain the depth of the fuel.

CHAPTER XI.

OIL FUEL FOR ROAD VEHICLES AND MOTOR LAUNCHES.

The advantages of oil fuel for raising steam in the comparatively small boilers used for motor lorries, fire-engines, motor buses, steam launches, and the like, are not so obvious as when used for larger powers, considering that whatever fuel is used the difference in the cost of running with small powers is not a matter of very great importance. The leading feature in favour of oil fuel in this connection is undoubtedly due to the rapidity with which steam can be raised, the steadiness with which it can be maintained, and the absolute and instant control over the fire, the last remark applying more especially to motor waggons, and the first to fire-engines.

The use of oil fuel, however, requires a somewhat more ample furnace capacity than when using either coal or coke; also it is not desirable that the exhaust from the engine cylinder should be led into the funnel when using oil, as the necessary supply of air is automatically induced by the burner itself.

In regard to the best form of burner for this application, it would seem that from the point of view of simplicity the steam jet is the most suitable, seeing that any higher degree of economy that can be obtained with air- or pressure-jet burners is of no great moment. But up to the present there cannot be said to have been much headway made with the use of oil fuel for steam road cars, lorries, or even for steam launches.

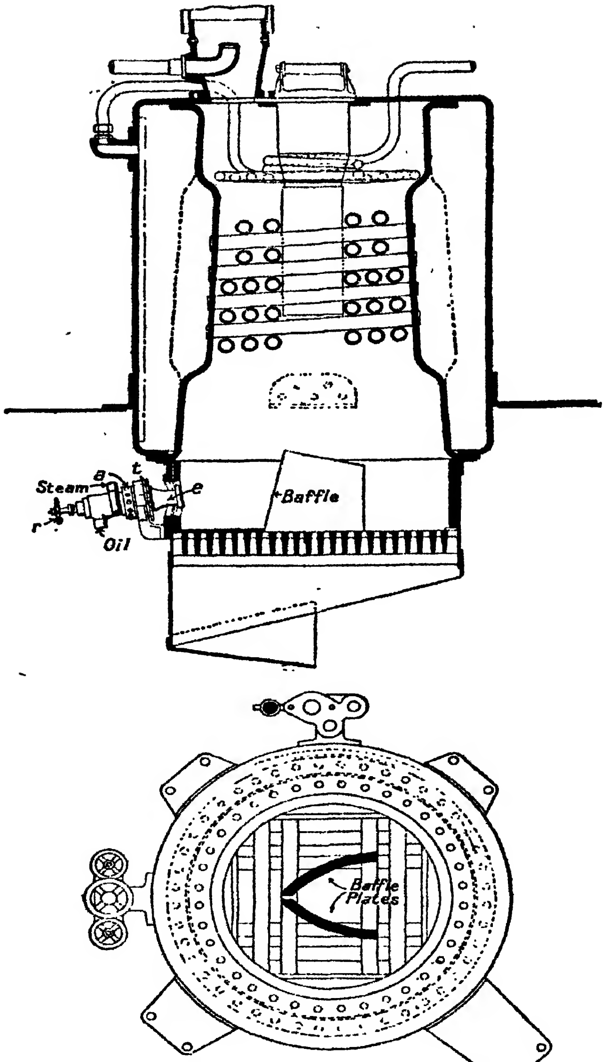


Fig. 99.—Motor lorry boiler arranged for burning oil fuel.

A typical example of steam lorry boiler (known as the Sentinel) adapted for oil-firing with a steam-jet burner is represented in the elevation and plan views, fig. 99.

In this application a Kermode steam-jet burner, shown in detail by fig. 100, is used and will be seen not to widely differ from the illustration of this type of burner (fig. 29) as used for stationary and locomotive boilers. In its application to the purpose now under consideration, the burner is fixed at a slight angle in the opening usually provided for stoking with coke, and, as this is extremely low down, presents another advantage for the use of oil, owing to the comparative ease of regulating the fire. The most notable difference, apart from the more capacious combustion chamber, as compared with a coke-fired boiler, is the use of baffle plates on the grate for the purpose of diverging the flame upwards and centrally against the series of water tubes above.

The oil valve *v* (fig. 100) regulator wheel *r* is connected up to within easy reach of the driver by a pair of sprockets and a short length of chain. Other adjustments, such as the lengthways position of the flame nozzle *e* by the star nut *t*, and the inflow of induced air by the perforated strap *a*, do not require to be changed on the road.

In action, the oil, which may be either kerosene or preferably one of the cheaper fuel oil grades such as gas oil, enters centrally, and has a whirling motion imparted to it by the stem of the oil valve *v*. Steam enters round the hollow cone, shown separately at *n*, and so preheats the oil, thus facilitating its thorough atomisation by the steam jet before admixture with air.

This same type of burner is shown in fig. 101, applied to a Merryweather steam fire-engine, a purpose to which oil-firing is more particularly adapted than perhaps any other adaptation of motor traction, for the reasons already stated. The burner J, which is fitted opposite an opening in the ash-pan, draws its supply of oil through E from the tank H, and is supplied with steam from A, the pressure (16 to 20 lbs. per square inch) being regulated by the valve B. A gauge D is provided to show the exact pressure under

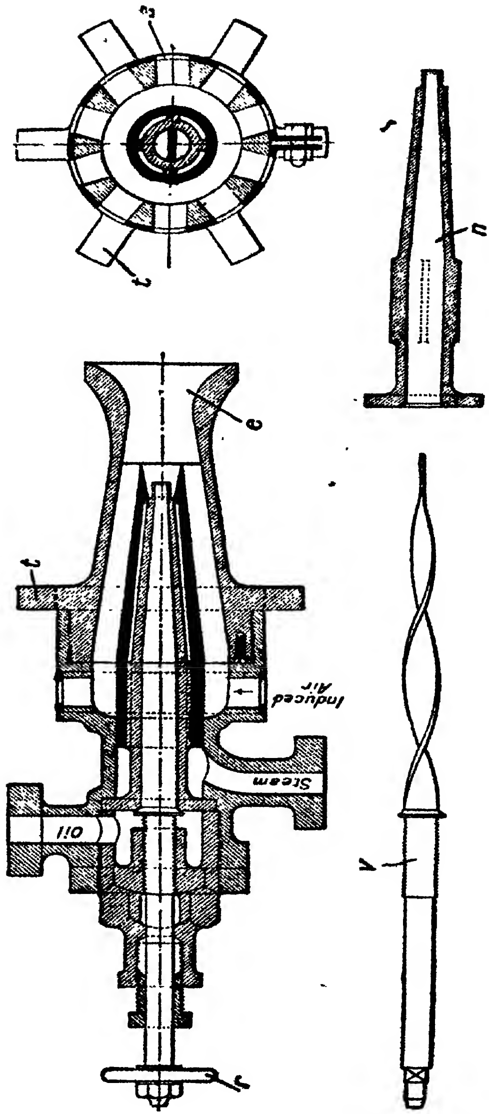


FIG. 100.—Kermode steam-jet burner for motor lorry.

which the jet is working. The tank I is for feed water, and the fire-door K for use when required to run with coal or coke.

One objection to jet burners when used for automobile purposes is the time required before the baffle block in the

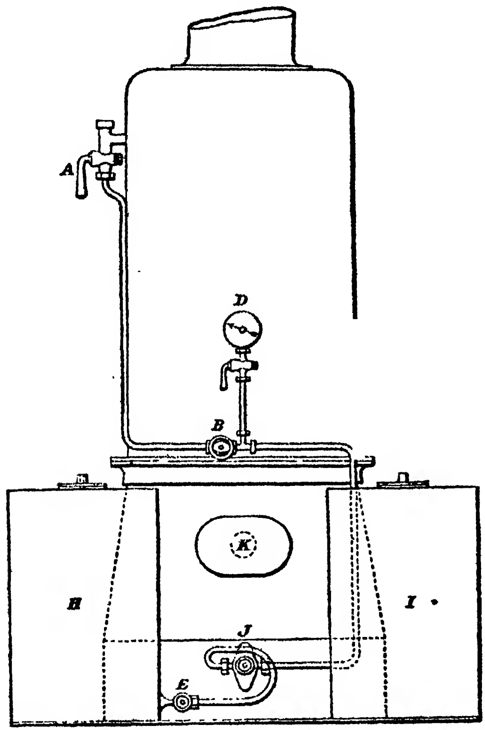


FIG. 101.—Merryweather fire-engine shown arranged for oil fuel.

furnace can be raised to a temperature high enough to obtain complete combustion, although this is reduced when compressed air is used at starting. On the other hand, when once properly started, a jet burner has the advantage over any form of blow-lamp or vapour burner, (1) for the reason that a jet nozzle is less liable to get choked than

the nipple of a blow-flame burner; (2) that a jet burner requires no vaporiser; and (3) can use the cheaper brands of oil fuel.

One of the advantages resulting from the use of oil fuel is that steam pressure can be maintained with greater ease and steadiness than with coal, and with an entire absence of sparks and flying cinders; also, less attention is required while at work, and no cleaning out on returning to the fire station.

The usual time required to get up steam from cold to the working pressure of from 100 to 120 lbs. per square inch is from five to seven minutes, for average size engines. It is customary to use either a gas or oil pilot burner located in the furnace, by which means a steam pressure of about 20 lbs. can be maintained constantly, two or three minutes then sufficing under these conditions to obtain the full working pressure; a gallon or so per twenty-four hours is found to be sufficient for this purpose.

Although limited in heating surface, the transmission of heat in thermal units has been proved to be comparatively high in boilers of the fire-engine vertical water-tube type, the evaporation from cold being 6½ lbs. per pound of coal, as ascertained on a six hours' full power test, and from 8 to 9 lbs. per pound of kerosene. However, owing to the reduced weight of petrol-motor fire-engines, these are now largely taking the place of steamers, despite the advantages of oil-firing. Indeed, it would seem that for automobile purposes there can be but little or no advantage from the point of view of economy in the use of refined burning oil of the paraffin or kerosene grades, for, although this fuel is flash-proof and obtainable at half the cost of motor-spirit, the consumption power for power of a paraffin-fired steam motor is practically double that of an internal combustion motor using either paraffin or motor-spirit; despite which fact much endeavour has been expended on the perfection of paraffin burners during the past ten years or so, most of which, almost without exception, have been constructed to operate on the blow-flame or pressure vapour principle, in which the oil is fed under pressure through a vaporiser situated over the flame produced from the combustion of superheated oil vapour issuing from a nozzle consisting of

an easily removed nipple having a small orifice controllable by a pin valve. The difficulty in most of such burners is that of preventing the restricted vapour outlet from getting more or less clogged from time to time, thus varying the intensity of the flame independently of the position of the oil regulator.

It is noteworthy that at the present time, as the outcome of considerable experience, many of the makers of steam-propelled commercial motor vehicles have abandoned this type of burner in favour of an atomiser burner, when required to run on oil fuel. Also that for pleasure cars, motor launches, and the like, where economy of fuel ranks lower down in importance than smooth and silent running, steam motors with blow-flame, paraffin-fired generators—such as in the Sheppee, Oswego, Stanley, White, Pearson-Cox, Gordon, and other cars; the Lune Valley motor launches, and the Darracq-Serpollet, Chaboche, and Clarkson motor buses,—although still surviving, have for the most part been superseded by either petrol or petrol-paraffin motors.

The method of regulating the intensity of the flame in kerosene or paraffin vapour burners is generally by a long tapered valve under the nozzle, through a very restricted aperture in which vapour is forced out under a pressure of from 30 to 40 lbs. per square inch into the open mouth of a mixing tube, thus inducing a current of air sufficient to produce a bunsen or blue flame. In the Sheppee, Turner-Miesse, Toward, White, and other burners, the vapour is blown into a hollow ring- or pan-shaped chamber which is perforated with outlets on the upper side, through which vapour and air to feed a flame of considerable spread issues in a number of streams, after first passing through a vaporiser coil or its equivalent.

A very ordinary type of paraffin vapour burner is illustrated by fig. 102; for this it is claimed that an evaporation of 15 lbs. of water from 212° F. per pound of paraffin can be obtained under proper conditions. It is essential, however, that a very ample flue and funnel area be provided, so that the hot gases may get freely away, otherwise the burner, which automatically induces its supply of air, does not get sufficient for complete combustion. According to

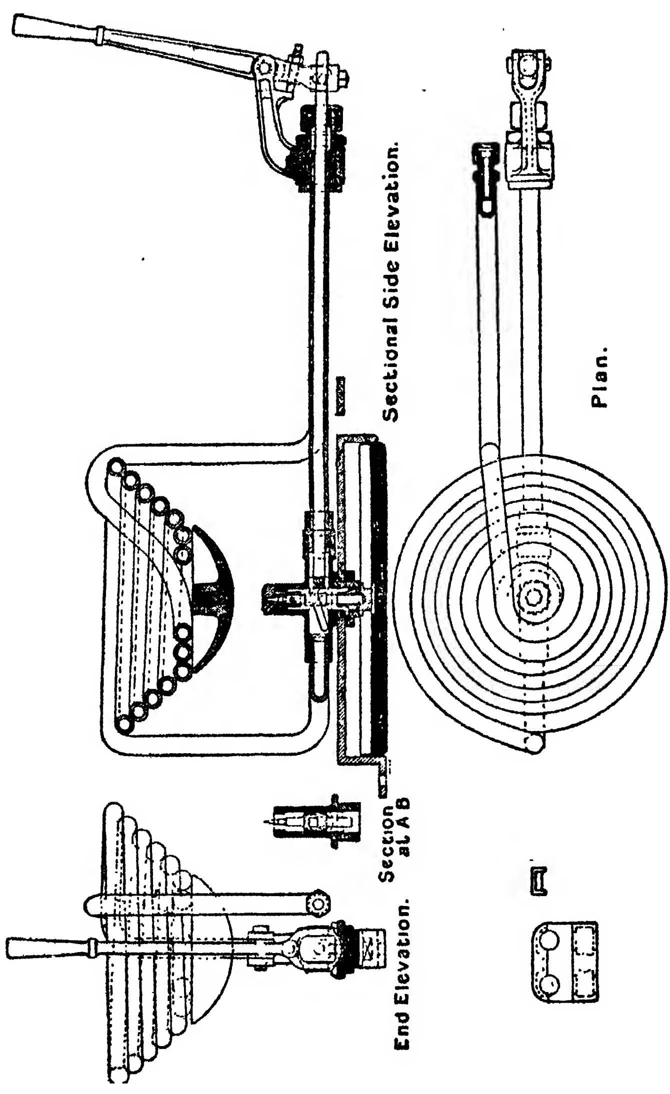


FIG. 102.—Details of Lune Valley vapour burner.

Mr Chas. T. Crowden—who has had a wide experience with paraffin burners of this type on motor lorries, fire-engines, and motor launches,—when converting a coal- or coke-fired boiler to steam with oil fuel, it is necessary to fit a funnel of nearly twice the capacity of that found sufficient for coal-firing, which, of course, invariably works with either induced draught by the exhaust steam, or, in the case of a launch with a condensing engine, with the help of a fan. Paraffin burners can be used—it is only fair to add—under some of the most trying conditions, with a surprising measure of success for small, high-speed launches, where obviously a very limited supply of solid fuel could be carried, and where the employment of forced draught would entail an additional difficulty.

In order to start a burner of this kind a little methylated spirit (by preference) is placed on the tray *t*, in quantity about 2 to 3 ozs., and by the time this has burnt out the coil will be as a rule warm enough to permit of the paraffin being slightly turned on by the regulator wheel *w*, which, on being partly rotated by means of the spindle *k* and crank at its end, moves down the valve *n*, thus allowing vapour to issue from the nozzle opening in the nipple *b*. The flame first impinges on a metal baffle and circulates through and around the steel coil *v*.

The burner, as shown by the sections, figs. 102 and 103, partly occupies the space usually taken up by the ash-pan, there being no fire-bars or fire-door required, and is thus well adapted for the cramped space usually allotted for the stokehold of a craft intended for speed. The fuel is carried in a drum which is fitted with an air pump for forcing the oil through the vaporiser coil and nozzle, the pressure used ranging from 30 to 40 lbs. per square inch, to obtain the best results. The oil enters at *p* at the top of the coil, the lower end *r* being connected to the regulator box under the nozzle.

In order to clear an obstruction in the restricted passage way for the vapour, the valve is moved up and down sharply, the baffle *f* being usually sufficiently hot to prevent the flame from being extinguished. In fig. 102 the movement to the vapour needle is obtained by a wedge at the end of a reciprocating control rod, and in fig. 103

by a crank action with rotary control spindle, which is freer and easier to work when the gland is screwed up to prevent vapour leakage. On the coil becoming choked (as happens sooner or later) it can generally be cleared by removing and placing it over a fire, and, while still at a dull red heat, tapping the coil all round, when the deposit will be sufficiently loosened to be blown out under pressure.

A considerable degree of ingenuity has been directed by Mr Clarkson in adapting paraffin fuel for the boiler of his smooth-running motor bus.[1] His burner, which is designed

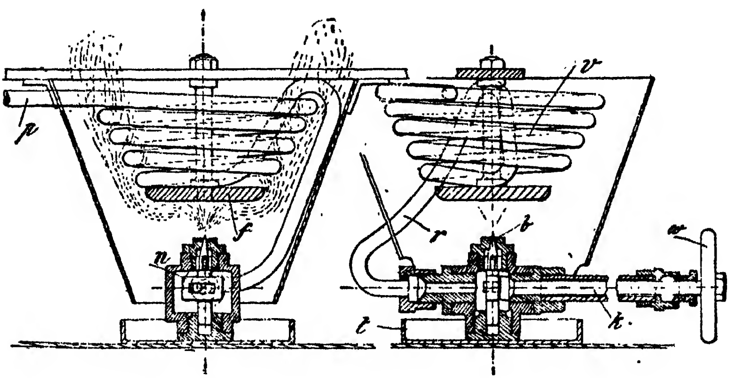


FIG. 103.—Paraffin blow-flame burner with coil vaporiser and vapour regulator (Crowden).

for using oils of the kerosene grades (paraffin lamp oils), differs in many particulars from any of the foregoing, although constructed upon the principle of supplying paraffin oil under pressure to a vaporiser: oil vapour thus generated issues in the form of a jet and is then mixed with air—on the bunsen principle.

The main fuel supply is carried in a tank which is not subjected to pressure, and can therefore be replenished quickly at any time without extinguishing the burner. The paraffin is pumped from the main tank into a pressure tank of solid-drawn steel, which is about half full of air. This forms a cushion, which equalises the flow, and keeps

[1] The National Motor Omnibus Co.

the burner fed when the car is standing and the pump is not delivering oil. The surplus oil delivered by the pump escapes through a spring-loaded relief valve set to about

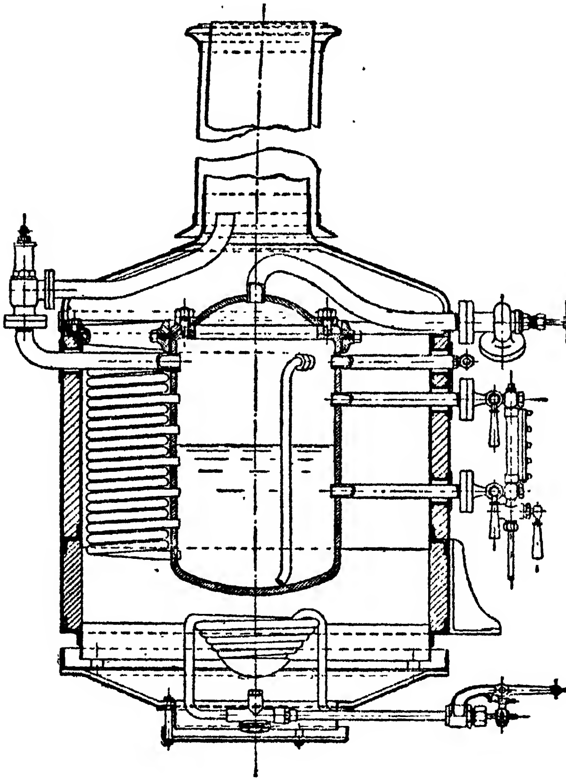


FIG. 104.—Section of Lune Valley water-tube boiler showing arrangement of paraffin burner.

40 lbs. pressure per square inch and returns thence to the main tank. To prevent loss of pressure by leakage through the relief valve when standing, a lock-up valve is provided, which, when closed and with the burner out of use, will

retain the pressure for long periods ready for the next lighting up. The air cushion in the pressure tank gradually diminishes with use, by "foaming" or absorption into the oil, and is replenished by a few strokes of a hand pump before starting each morning.

The oil supply to the burner (fig. 105) is connected with the lower end of the vaporiser coil; whence from the upper end the vapour is conveyed to the jet nozzle, the area of which is regulated by a wedge-shaped needle. This needle performs a dual function in assisting to keep the nozzle clear of obstruction, in addition to controlling the supply of vapour to the burner, and thus determining the size of the flame. The rate of combustion is governed not by the supply of oil, but by the supply of vapour. This is found to be more convenient in securing a proportionate admixture of air with the vapour for complete combustion at all rates of consumption, from the minimum to the maximum, and at all intermediate rates. The jet of vapour is directed along the axis of an inducing or mixing tube. One end of this tube is open to the atmosphere and the other delivers the mixture of vapour and air into the centre or body of the burner, in which a small pressure is maintained by the force of the vapour jet. This pressure in turn is derived from the pressure of oil in the supply tank. It follows that the pressure must be maintained practically constant to ensure regular results in the working of the burner. The mixture of vapour and air is permitted to escape from the body of the burner through a series of circumferential slots, the opening of which is controlled by a piston valve.

To obtain a correctly regulated supply of mixture it is necessary to form the jet nozzle either square or rectangular in shape, and to control the opening by a wedge-shaped needle having parallel sides which fit accurately into the nozzle. Then, as the wedge is moved to and fro in the nozzle, the area is diminished or increased in one dimension only, instead of in two, as would be the case with a circular orifice. This method of varying the area for the escape of the fuel mixture in strict accordance and simultaneously with the supply of vapour to the burner overcomes the serious difficulty of "back-firing" or "light

ing back." The simple explanation is that the velocity of efflux of the vapour mixture is maintained always in

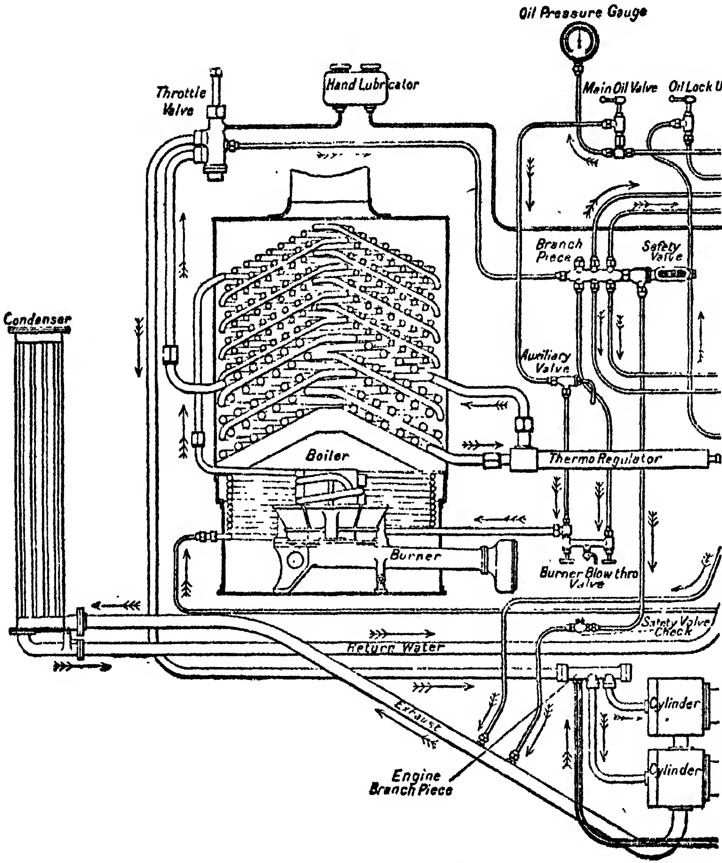


FIG. 105.—Diagram showing the Clarkson vapour burner applied to the boiler of a motor bus.

excess of the velocity of the propagation of flame. Hence the flame is kept outside of the burner.

Subdivision of the mixture is obtained by delivering

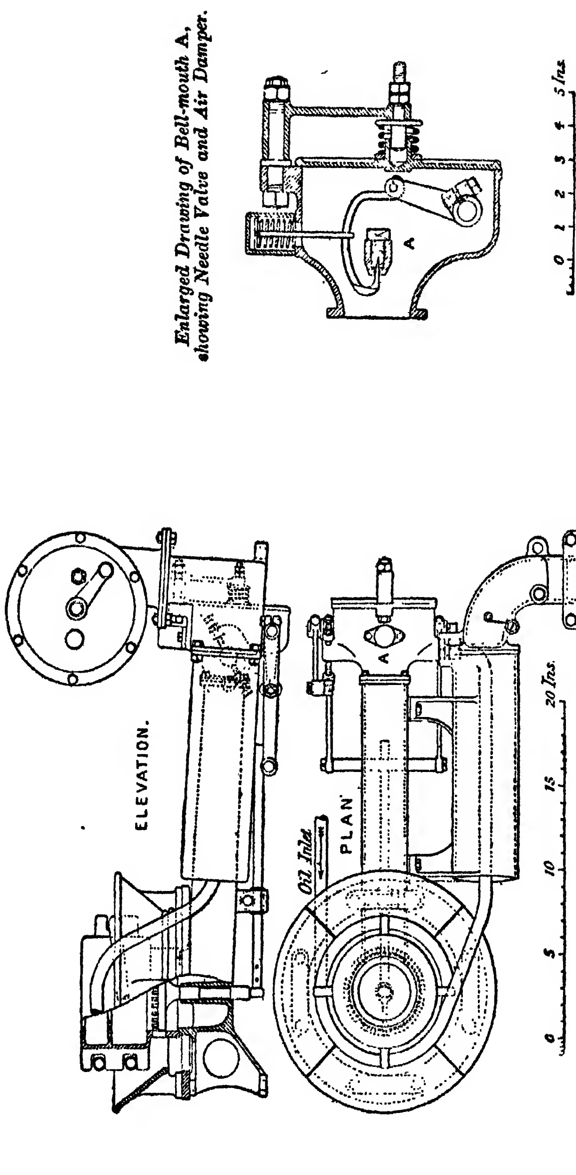


FIG. 106.—Clarkson vapour burner for motor bus.

it through a series of slots which facilitates the access of air to the flame by providing a number of air passages. Originally six slots were used, but better results are obtained with thirty. The flame, which is in the form of a basin, is received and steadied by a conical frustum, which becomes incandescent. This shelters the flame from irregularities in the air supply, and its radiant heat is focussed upon the vaporiser, situated within the hollow of the flame.

It is important to maintain the temperature of the vaporiser as evenly as possible, in order to ensure the vapour being supplied to the burner at constant density. This has an important bearing upon the intensity and regularity of the flame; a cooler vaporiser produces a heavier vapour which readily condenses, and which, by enriching the mixture, tends to the production of a luminous flame; and if cooled excessively causes the burner to smoke. When the vaporiser is heated too fiercely, the superheated vapour, being more highly expanded or attenuated, reduces the richness of the mixture, and tends to the production of a reddish flame of great local intensity. The total heating power of the burner is also reduced by unduly superheating the vapour, owing to the reduced weight of vapour then escaping through the nozzle; lighting-back is also caused, and the vaporiser soon becomes fouled by carbon deposit obtained by dissociation of the vapour. Excessive local heating of the vaporiser also causes the burner to surge, coupled with local interior fouling and exterior oxidation. It is preferable to make the vaporiser with a regular slope upwards, from the point where the paraffin enters, up to the highest part, whence the vapour is conveyed to the jet nozzle.

In order to start up the burner it is necessary first to heat the vaporiser to the working temperature, then to turn on the oil supply, and apply a light to the mixture. Preliminary heating is quickly done by a cast-iron starter box, containing several asbestos wicks, which are saturated with paraffin and readily ignite from a match. A current of air is blown into one side of the box, and into the other side a strong flame. The end of the flame is directed against the body of the burner, and in close proximity to

the mixer slots, so as to ignite promptly the vapour mixture as soon as it comes through. This arrangement will start the main burner in one minute or so, and the omnibus can move by its own steam in ten minutes from "all cold."

In the Pearson-Cox oil-fired steam car,[1] a three-cylinder single-acting engine K (fig. 107) is supplied with steam generated in a tubular boiler E, under which is located a

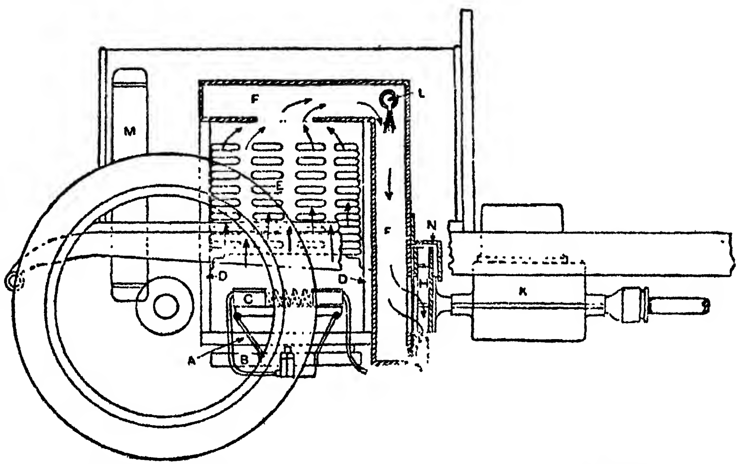


FIG. 107.—Diagram of Pearson-Cox kerosene-fired generator applied to a steam-driven motor-car.

paraffin vapour burner, consisting of the vaporiser coil C, one end of which is connected to a fuel reservoir maintained at a pressure of about 38 lbs. per square inch by a small air pump, and the other end to the burner nozzle shown in detail in fig. 108. Below the vaporiser is a slotted wind shield A, and tray B, the latter for starting. The fumes of combustion are drawn by a fan H from the generator casing D through the flue F, into which the engine exhausts at L, a radiator M being also provided for condensing part of the steam. But the most interesting feature is the burner; in this, it is claimed that the paraffin

[1] *The Autocar.*

is never heated beyond 500° F., and therefore no cracking or decomposition takes place; also that vapour leakage is reduced to a minimum by reason of the enclosed needle-valve control C D, which lends itself for locating the gland on the spindle D, which has only a small rotary movement, instead of on the valve stem, and in consequence there is no tendency for the vapour valve to stick fast. Now, as the taper needle C causes the flow of vapour to spread as soon as it leaves the

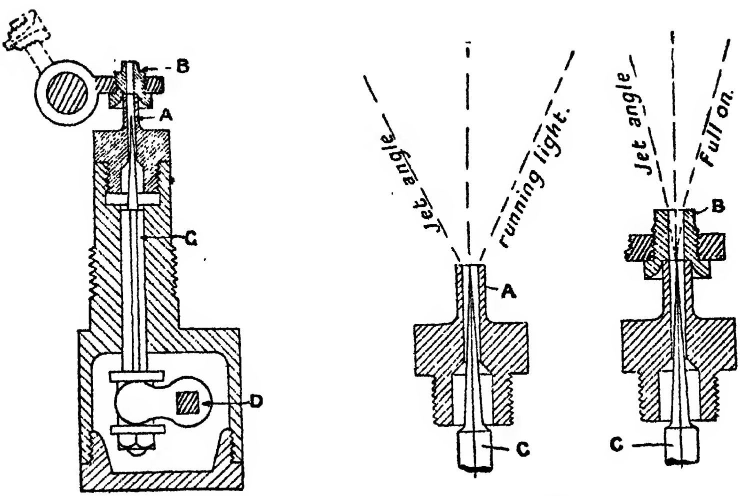


FIG. 108.—Details of Pearson-Cox burner nozzle.

nozzle A, a comparatively diffused flame is the result—quite sufficient for standing but not enough for running. Consequently a secondary nipple nozzle B is fixed like the arm of a lever on a rocking shaft that can be actuated through the usual lever arrangements by the driver, so that it can be swung over and come on top of the primary nozzle A. Though the nipple nozzle is of the same diameter as the other, the upper corner, so to speak, of its bore catches the flow of vapour just as it is spreading, and not only prevents dispersal, but tends to concentrate the jet. The effect, indeed, is much the same as that of a choke bore gun; the flame is prevented from spreading, and, being concentrated,

is longer, able to reach higher, and take effect upon the upper tubes of the generator. Without the nipple nozzle and with the burner turned down low, with the car standing, 1·5 pints are consumed to the hour, while with the nipple nozzle in the position shown, and burner full on, the consumption works out to 2·27 gallons an hour, which is capable of steaming an average car from 12 to 14 miles to the gallon of paraffin, according to road conditions. To start, the cold oil spray issuing at pressure from the jet can be ignited without trouble, and in a minute or two the vaporiser is hot enough for the jet to burn without smoke.

As will be seen, the problem of designing an oil burner suitable for the very exacting conditions demanded for success in the running of steam-propelled road vehicles is by no means as simple as may at first sight appear, and, judging from the research and keen attention that has been directed towards the solution of the burner problem, it would seem that the generation of steam for the comparatively small powers required by the automobile—whether in a flash, semi-flash, or ordinary type of boiler—presents difficulties of a nature not experienced in any other application.

The burner illustrated in fig. 109 departs from the usual practice, both in form and method, as followed in burners of this kind. In this blow-flame (paraffin) burner, known as the Werner, the vaporiser consists of an inverted hollow cone-shaped casting provided with ribs on the outside, and is supported by a tubular stem from the distributor containing a pair of vapour nozzles, so as to act as a diffuser for the flame produced. Within the outer tube A—used to connect the top of the vaporiser by means of the tube C with the distributor branch carrying the two nozzles D, D[1]—there is a smaller tube F for the supply of paraffin. The outer stem A is plugged at its upper end, this being drilled to receive two small tubes C and F, the one extending upwards to within a short distance of the top of the vaporiser to supply the two nipples D, D[1] with vapour, and the other tube F downwards for the supply of oil to the bottom of the vaporiser. The novel feature of this burner consists in filling the vaporiser with metal shot (preferably copper), up through which the oil in the process of being vaporised steadily percolates; and as the area for

the passage of the vapour increases as it rises and expands, surging—which is a common fault with most blow-lamps

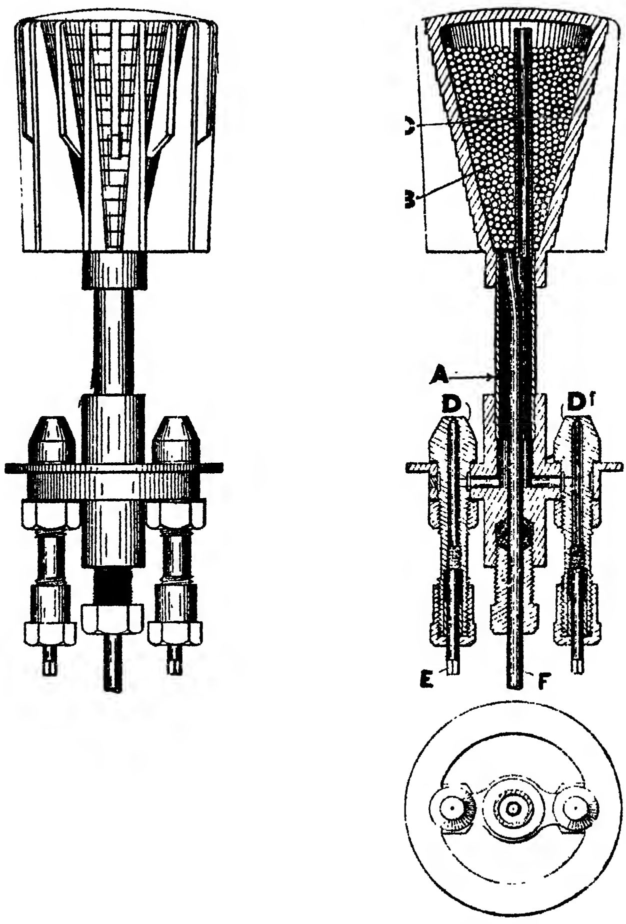


FIG. 109.—Werner twin-jet blow-flame paraffin burner.

when not subjected to the right treatment—is prevented. Each nipple or vapour nozzle is fitted with a needle valve

E, in order that the apertures for the vapour jets can be regulated, and permit same to be cleared at any time.

Owing to the fact that the oil while passing up through the vaporiser is very little in actual contact with the inner surface of the cone, the outer may be heated to dull redness without cracking the oil, and consequently produces little deposit; the interstices between the shot are also automatically maintained by the vibratory action of the motor and vehicle in motion.

But the most important feature associated with the Werner burner consists in the method adopted for feeding the oil. Unlike all other burners operating on the blow-flame principle, in which the fuel (paraffin or kerosene, such as used in wick lamps) is supplied at constant pressure, the fuel feed in this burner is effected by a miniature variable stroke pump similar in construction and action to the form of pump used for supplying the water feed to a flash boiler; and in this case the burner and steam generator pumps are arranged to synchronise, so that the intensity of the flame is caused to vary in close degree with the volume of water to be evaporated. Between the burner vaporiser cones and the lower row of tubes of the steam generator there is a thick perforated fire-brick screen that serves the double purpose of not only equalising the intensity of the flame, but stores sufficient heat to automatically light the burners if extinguished from any cause, or even after being closed down for some time.

For small launches and pleasure boats many attempts have been made to improve on water as the evaporative medium by a liquid of lower latent heat value, such as ammonia, alcohol, or mineral spirit. Theoretically, a higher rate of evaporation can be obtained by this means owing to the lower temperature range, less heat escaping up the funnel, to the condenser, and by radiation. In practice, however, such leakages of vapour occurs from imperfect joints and fittings that not only may the efficiency be lower but fraught with actual danger, especially in a closed engine-room. Power development has consequently not made much advance in this direction, the only notable application on this principle on record being the Yarrow-Zephyr, Escher-Wyss, and a few other motor boats made before the perfecting of the high-speed petrol motor. In most of these, known as vapour motors, a vertical

3-cylinder reversible engine having a comparatively large feed-pump was used in combination with a tubular generator. As efficiency depends on low boiling temperature it is necessary to use a liquid of high volatility in the generator to obtain the full advantage, although ordinary paraffin can be used in the burners. The possible economy in running a vapour motor over that of steam is but small, the principal gain being the time required to get under way.

The tendency at present, however, in regard to liquid fuel for motor-boats, road vehicles, field tractors, and small stationary engines is more and more towards the use of internal combustion motors, owing to their reduced weight, more automatic operation, and greater economy; so pronounced is this, indeed, with motors run on the more volatile grades of liquid fuel—such as petrol, otherwise known as benzine, essence, or gasoline, and constituting the lighter products of crude petroleum—that despite the fact that its cost has more than doubled since the war, and costs more than twice as much as the flash-proof grades known as lamp oil, kerosene, paraffin, etc., of which the supply is equal to the demand, the spirit series are preferred to the safer flash-proof series for pleasure cars, and indeed for all motor vehicles used in towns, owing to its greater cleanliness and peculiarly adaptable nature to the requirements of a simple form of motor.

It is estimated that the world's consumption of motor-spirit now exceeds upwards of a million tons, apportioned as to 450,000 tons in the United States of America, 300,000 in Europe (280,000 in Great Britain, and 120,000 tons in other countries), of which all but about 5 per cent. of benzole—distilled from coal-tar oil—and less than 1 per cent. of alcohol—such as methylated spirit—are derived from crude petroleum, of which the spirit series constitutes from 3 to 20 per cent. Owing, however, to the inflammable nature of motor-spirit, the utmost importance attaches to care in its use and storage, especially having regard to the fact that in Great Britain alone there are over 500,000 motor-cars, commercial vehicles, motor-cycles, motor-boats, and aeroplanes, besides many thousands of petrol-motors used for lighting and general purposes. In this country the necessity for this was early realised, and within a year of the passing of the

Locomotives on Highways Act, in 1896, a regulation was issued by the Secretary of State as follows:—

1. That the amount of petrol stored shall not exceed 60 gallons, including that contained in the tanks of the car, in any one storehouse.

2. In the event of a storehouse being within 20 feet of any other building, whether in the occupation or not of the person storing the petrol, or within 20 feet of any timber stack or other inflammable goods, notice shall be given to the local authorities under the Petroleum Act, 1871. This restriction does not apply to petrol kept in the tank of the car. Every storehouse shall be thoroughly ventilated.

3. Two storehouses within 20 feet of each other are deemed to be one, and therefore only 60 gallons may be stored in buildings so placed.

4. The storehouse shall not form part of a dwelling or be in connection with a place where persons assemble.

5. In a storehouse, or in any place where a light locomotive is kept, petroleum spirit shall not be used for cleaning or lighting, or for any other purpose other than as fuel for the engine.

6. All vessels, not forming part of a car, when used for keeping or conveying petrol, shall bear the words "Petroleum spirit, highly inflammable."

7. Petroleum shall not be allowed to escape into any inlet or drain communicating with a sewer.

One of the greatest dangers associated with the storage of motor-spirit—*i.e.* liquid fuel from which an inflammable vapour may be produced at temperatures below 100° F.—arises from the admission of air to the tank as it is being emptied, and applies more especially to the storage of large quantities in towns, as by motor-omnibus, cab, and carrier companies, etc., the importance of which will be recognised on considering that the General Omnibus Co., who alone own upwards of 2500 vehicles, have storage for 80,000 gallons of motor-spirit at their various depôts. There are two methods by which the admission of air can be obviated—viz., displacement by water over which the spirit floats, and by an inert gas such as carbonic acid. Of these, the first named, and known as Snell's

hydraulic system, has been extensively adopted in this country and the United States. This, as the title implies, depends upon the difference in specific gravity of water

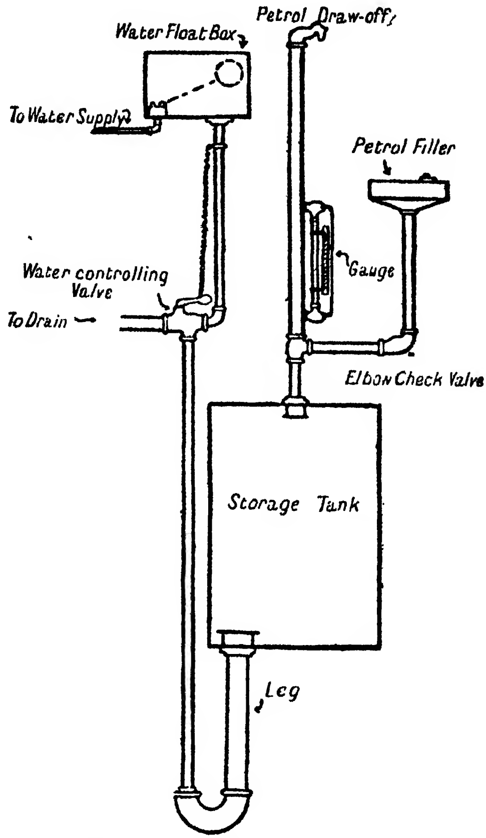


FIG. 110.—Diagram of Snell's hydraulic system of petrol storage.

and oil, as, for example, 12 inches of water will balance approximately 17 inches of petrol.

In preparing the system for operation (*vide* fig. 110), it is first filled with water by raising the water-controlling-

valve lever, which movement closes the port leading to the drain and opens the port leading to the water cistern, thus allowing the water to pass from the cistern through the valve to the bottom of the leg of the storage tank and up this leg into the tank, where it strikes a deflector and spreads evenly. The entering water displaces the air, forcing it up the petrol delivery pipe and out of the delivery nozzle. The water-controlling valve lever is held up until water appears in the gauge-glass, when the tank is full of water and all air expelled. The lever is then lowered and closes the port of the water-controlling valve which communicates with cistern, and opens the port which communicates with drain, thus allowing the water in the petrol pipe above the water-controlling valve to return to the storage tank, and discharge an equal volume of water into the sewer; the storage tank is then ready for being filled.

To fill with petrol:—Unscrew the half-hose coupling on the petrol filler, connect up tank waggon with flexible hose and allow petrol to run in, or, if filling from barrels, simply allow petrol to flow into open filler. The petrol passes down the piping into the top of the storage tank, where it strikes a deflector and spreads evenly over the surface of the water, forcing the water out of the tank through the water-pipe and water-controlling valve to the drain.

Petrol can be poured in until the storage tank is completely full of petrol, but it cannot be overfilled, thereby forcing the petrol into the sewer, because the water column from the water-controlling valve down the pipe to a point level with the bottom of the storage tank is of sufficient length to balance a column of petrol from the bottom of the storage tank up to the top of the petrol. Therefore when the tank is full of petrol no more can be poured in, or, if using barrels, it will overflow at the filler, the same as any other full tank.

To draw petrol:—Depress the water-controlling-valve lever, which closes the water-discharge port and opens the port connecting the cistern, thus allowing the water to pass into the tank under the petrol and force the petrol from the top of the tank out of the delivery nozzle. When the desired amount has been drawn, release the lever and the

flow will instantly stop, and the petrol in the delivery pipe return to the storage tank. After all the petrol has been drawn, water will flow up the delivery pipe to the same level as the water in the cistern, or about 9 inches below the level from which the petrol is drawn. Therefore no water can be drawn with petrol from the tank. The available head of water is kept constant by the float valve in the cistern, which may be connected with the town water supply.

According to the method of safeguarding a partly emptied motor-spirit storage tank, by admitting a corresponding volume of inert gas, as used by the Paris Omnibus Co. for the storage of benzole:—The fuel is protected from any risk of explosion by a layer of carbonic acid gas, which occupies the upper portion of each of the reservoir tanks. The regulations with regard to the storage of fuels of this nature in Paris are very strict, as in England, and by employing the Rolland-Mauclere system considerable space is saved, as the regulations do not require the storage-plant to be situated so far from any other building as would be the case if a system were adopted in which less efficacious measures were employed for ensuring safety. Referring to the diagram, fig. 111,[1] the supply of fuel is stocked in reservoirs, lettered R, and the whole of the operations of filling and emptying these reservoirs is dependent upon apparatus designed to affect the pressure of the inert gases which protect the fuel. A tank waggon W is first drawn up into the position shown and connected up by a pipe with the reservoirs; the compressor C (worked by a direct-coupled electric motor) is then put into action, and this draws out a portion of the inert gas in the reservoirs and compresses it in the accumulator A, when a corresponding volume of benzole flows into the reservoirs to replace this gas. To prevent air from being sucked into the reservoirs, the security apparatus S is fitted with a float, which, so long as the apparatus is full of liquid, is raised from its seat and does not interfere with the flow. When the level of the liquid sinks the float subsides and will not allow air to pass. The fuel is now safely stored in the reservoirs under a seal of inert gas,

[1] *The Autocar.*

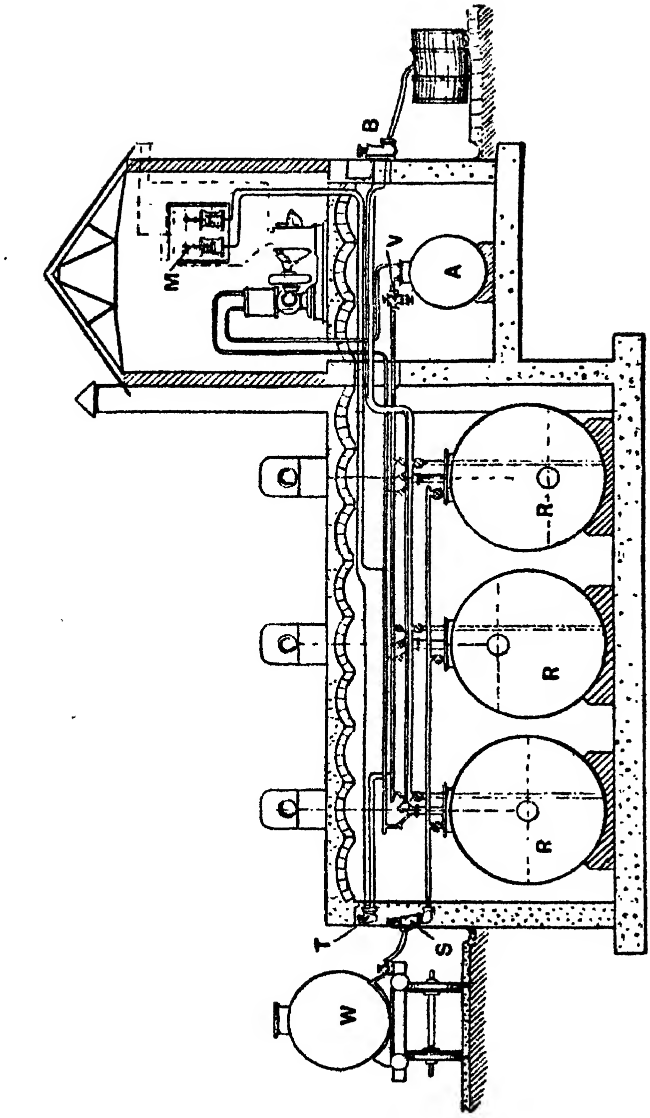


Fig. 111.—General arrangement of the Rolland-Manclere system of fuel storage

and no breakage of the pipes or other accident can render it liable to leak or explode. This state of affairs is maintained automatically by means of an apparatus M in the nature of an automatic switch, which puts the compressor into action if the pressure in the reservoirs rises above that of the atmosphere. At T there is a three-way cock which normally connects the reservoirs with M. When this cock is turned into its second position the gas compressed in the accumulator A is passed to the apparatus M; in this way the compressor is put into action at the beginning of the operation of filling up the reservoirs, after which the cock is turned to its first position. The apparatus M acts only under the influence of variations of pressure and not through any mechanism susceptible to derangement. Any accident to it does not put the compressor into action, but merely prevents it from operating. To draw off fuel, all that is necessary is to admit inert gas from the accumulator A to the reservoirs R, passing it through the reducing valve V. The liquid then rises in the pipes and runs out through the valve B, whence it passes through flexible piping into the fuel tanks of the buses. After every withdrawal of fuel the compressor automatically restores the inert gas in the reservoirs to atmospheric pressure.

For ordinary garage service a very convenient apparatus is supplied by the Anglo-American Oil Co., consisting of a riveted tank which is fixed outside the buildings at a level 2–3 feet below the floor and cemented in; over this is fixed a supply pump having a valve plunger connected to an operating gear so that a car can draw up alongside and have its tank refilled on the metre system with the minimum of trouble, which, besides avoiding all possibility of spilling, contamination, or fire risk, shows the exact quantity supplied indicated on a recording dial.

CHAPTER XII.

OIL FUEL FOR METALLURGICAL AND OTHER PURPOSES.

OIL fuel should form an unequalled medium for smelting metals of various descriptions, especially the more valuable ones. The cleanliness of the fuel alone recommends it for use in smelting, and it has been adopted in quite a number of instances in this and other countries. But the great objection to it is its cost, though the economy that can be effected in the metal itself is one point which would largely counterbalance it. Oil fuel has also found extensive use in smelting the baser metals, and we cannot do better than give a brief record of these applications here. In this connection it is of some interest to know that as far back as 1888 an oil-fired regenerative furnace was built in Scotland by Riley and Dick for heating steel and iron forgings; also that about this time Nobel of Petrograd, Wittenstrom of Motala, and Ostberg of Stockholm experimented with residual oil and naphtha-fired furnaces for melting metals. According to their experience, the use of liquid fuel promised several advantages:—(1) A petroleum hearth does not give off any noxious sulphur gases; (2) it occupies less space, so that more smiths can be accommodated in the shop than with coal hearths; (3) it can be easily fitted; (4) it is cheaper; and (5) much more intensive than coal, especially in nail smithies, since a number of pieces of iron can be heated together and the work goes on continuously.

For example, the hearths in the Ufa (Russia) railway repairing shop, eight in number and employing 20 smiths,

were formerly fired with coal exclusively; but as the work increased and more accommodation became necessary, oil-firing was introduced.

The construction of the smithy hearth used is illustrated in the sectional view, fig. 112, and consisted of a solid angle-iron framework, mounted on iron pedestals. This framework carried a course of brickwork, 4½ inches high, at the two extremities of which were the generator B and the flue C, the iron being heated in the part D. The generator B consisted of a jacketed iron case, into the two opposite

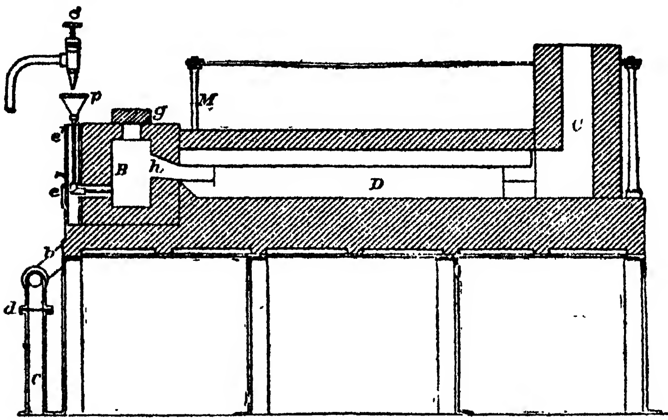


FIG. 112.—Longitudinal section of Nobel metallurgical furnace.

sides of which debouch the branches of the air conduit *c*, fitted with a damper *d*. The two walls of the case were provided with semicircular apertures, *e*, *e*[1], the former fitted with a damper and serving as a peep-hole for watching the progress of the fire. The atomiser consisted of two iron pipes, one of which was wedged firmly into the inner wall of the case and served as the air-blast nozzle; whilst the other was formed of two parts, set at right angles, one part acting as the oil nozzle and the other terminating in the smaller funnel *p*, which was filled with oil from the tap *o*. The generator case is open below, and the sole purpose of the side walls is to strengthen the fireproof lining, this being provided with two fireproof orifices, *g*

and *h*, of which the first named served for the ignition of the mazout on starting to work, whilst *h*, which is taper and slopes down towards the space D, conducted into the latter the gases produced and ignited in the generator B. In order to increase the retention of heat in D and ensure the better heating of the work, the bottom of the hearth was filled with broken fire-brick. The chamber D was fitted with a cover of fire-brick set in an iron frame, this cover being arched to facilitate the access of the flame to the material to be heated.

In working these hearths the mazout was the fuel used, and was lighted by throwing a small bundle of burning oil-soaked rag through the orifice *g* into the generator, the register in the air pipe being opened a little, and a fine stream of mazout allowed to run into the funnel *p* by turning on the tap *o*. The oil encounters the current of air, is atomised, and ignites at the burning rags. The complete admixture of oil and air is assisted by the position of the orifice *h*, which is on a somewhat higher level than the atomiser. Until the walls of the generator are fully heated, the flame was allowed to stream through *g* and *h*, but as soon as the hearth began to get white hot, the hole *g* was closed. The temperature of the hearth could then be adjusted to working strength by regulating the air damper and the oil tap, the best results being obtained when the air pressure in the pipe measured 2 inches water gauge and 1¼ inches in the generator: under these conditions the consumption of oil was 40-42 lbs. per hour. The double walls of the generator case serve to heat the incoming air, and thus economise fuel.

For the manufacture of sheet-iron oil-fired furnaces had been in use at these works, which differed very little in construction from the usual gas furnace. At the back of the arch, for instance, there was an opening to admit the oil sprayer. The sprayer was so arranged that it could be moved in any direction, while there was no possibility of air entering, except through the sprayer. The products of combustion travel through the side flues, and thence to the chimney. Each furnace had its own chimney, the diameter of which was 2 feet and the height 40 feet. As a rule the chimney was shorter than this, as with petroleum fuel less

draught is required, and the fire can be so regulated that practically no smoke is observable.

At the back of the furnace an opening is made to regulate the temperature and to increase or decrease the supply of fuel or air. Care should be taken that the *sprayer is not more than about 20-24 inches above the level of the ingots. As a rule the furnace could be heated* very rapidly—and made ready for working in from 2½ to 3 hours, and not more than from 4 to 5 cwts. of mazout were required for every three ingots dealt with; the gas furnace, on the other hand, generally took from 9 to 10 hours to prepare for working. In the oil-fired furnace the ingots are put in the same way as in a gas or wood furnace, but with this difference, that whereas the ingots in the two latter descriptions of furnace are laid on their sides, in the former they are laid flat. The ingots are evenly heated throughout, so that the percentage of spoilt ingots is considerably less than when gas is used. Not only this, but the wear and tear of the rolling mills were found to be much reduced, as, for instance, in 1896–97, when wood-firing was used, out of five rolls in the mill, four were broken; while in 1897–98, when mazout was used, not a single roll was broken, and the work turned out was superior. By the use of gas fuel, that part of the ingot which lies at the back of the furnace always attained a higher temperature than that in front, and with Siemens-Martin steel excessive oxidisation was noticeable in the back part of the ingot.

In the petroleum furnace, on the other hand, the temperature is always regular throughout, and with Siemens-Martin steel no trace of oxidisation was apparent. It may be doubted whether it is possible to distribute the heat evenly over a space of 3 feet square, as the flame was concentrated in the centre, and being forced by pressure, was spread over the whole area, and this was proved by the fact that, whereas the iron sheets showed a difference of thickness amounting to 2 mm., the front measuring 24 mm. and the back 26 mm., or a difference in weight between the front and back of the ingot of 2 lbs., when oil-fired was introduced this difference entirely disappeared.

The quantity of fuel used for the furnace represents

1 ton of residuals, or approximately 4 gallons per hour per ingot. The quantity of iron treated averaged 7 tons in the twenty-four hours.

In the year 1901 a small oil-fired furnace for metallurgical purposes,[1] and primarily for smelting tungsten and copper

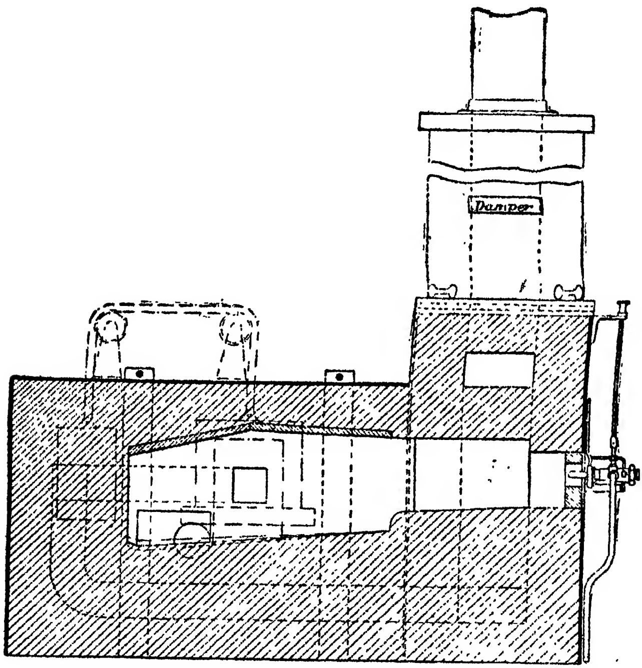


FIG. 113.—Longitudinal section of Holloway's smelting furnace.

ores, was erected and worked by Holloway, Lake & Currie. This furnace was a small one of the reverberatory type, and the method of supplying the oil, pulverising and igniting it, was of the simplest. The burner, in fact, was nothing more than a simple mechanical device for injecting oil and air into the furnace. One of the chief points about this apparatus was the small size of the combustion or gasifying

[1] *Petroleum Review.*

chambers, namely, 8 × 7 × 9 inches, which may be seen from the sectional illustrations, figs. 113 and 114. The furnace was worked by a blast obtained from a Roots blower, and heated by the waste heat. The system employed permitted of a low-pressure air-blast, though a wide range of tempera-

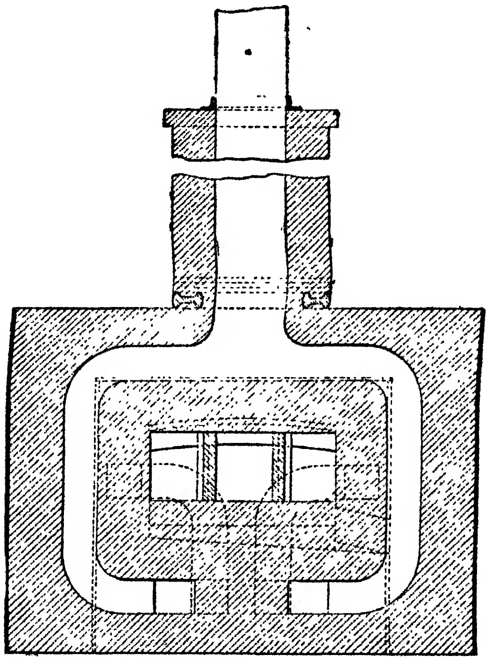


FIG. 114.—Transverse section of Holloway's smelting furnace.

ture could be obtained. The results of the working of this furnace proved that a reverberatory furnace having a hearth 5 feet by 2 feet 6 inches could be run at a temperature just below the fusion point of cast-iron, for a consumption of 2·8 gallons per hour, and an air pressure of from 2 to 3 ozs., and that a high-temperature crucible furnace, capable of holding three 150-lb. pots, could be worked for seventeen consecutive hours at a temperature

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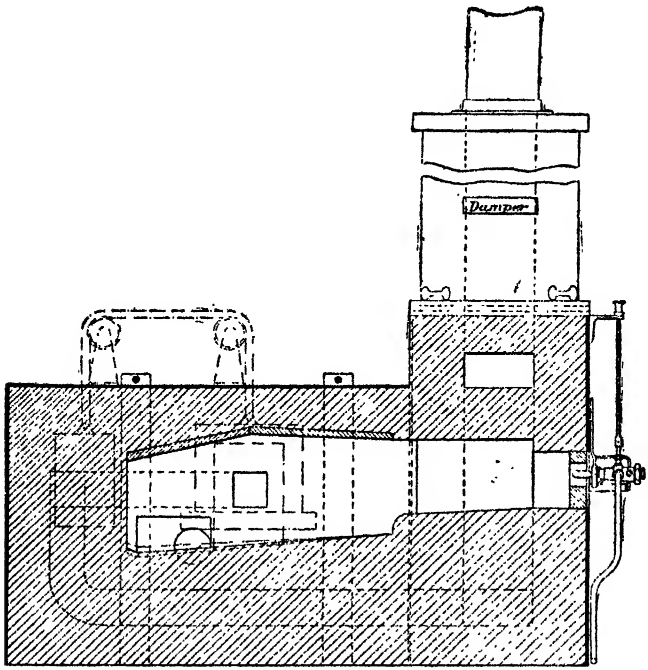

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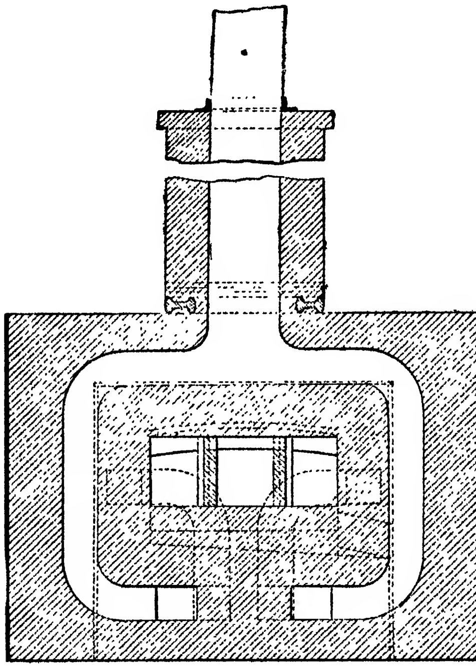

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furnace, 35 by 16 feet in the clear, a flame of 6 feet or even more in length is needed. The burner has to be adapted to the furnace and to the work to be performed. Hence, one will find at metallurgical establishments a great variety of burners, or at least a great variety of sizes of burners. A very practical and easily made burner consists of two concentric pipes, the smaller one being the oil pipe, and the larger one the steam-carrier. By this arrangement the oil pipe is steam-jacketed, and the temperature of the oil is raised to such a degree that its fluidity is very much increased, and part of the lighter oils become gases. All this tends to break up, more or less, the viscous oil into minute particles, which ignite readily when brought in contact with air.

In fig. 116 is illustrated a portable form of riveting furnace with a Holden burner which may be operated by compressed air or steam, whichever is most convenient. In this, the regulating valve C, coupled between the compressed air or steam-supply pipe and the injector, enables the exact amount of air or steam to be admitted for spraying and atomising the oil, an 8 hours' supply of which is contained in the tank above. Rivets are fed in at the top hole of the furnace, where they are first heated by the waste gases, and then passed through to the lower chamber, where they are submitted to the full heat of the flame; and when sufficiently heated they are removed through the bottom door. To start the Holden furnace, lighted oily waste, or similar combustible material, is placed in the lower chamber, and the valves opened very gradually and regulated until a clear fire is obtained without smoke. In fig. 117 there is also illustrated a sectional elevation and plan view of a small Taite & Carlton crucible furnace which has given excellent results in working; this is also fitted with a Holden burner.

Oil-fired furnaces worked on the reverberatory system have been in use for many years. These consist as a rule of iron cylinders lined with refractory material, and carried on trunnions so that they can be tilted to pour out the metal, the oil being sprayed in by means of an air blast at one end. This type of furnace is frequently built double —as illustrated in fig. 118,—consisting of two independent

chambers, the oil being blown into them alternately. These

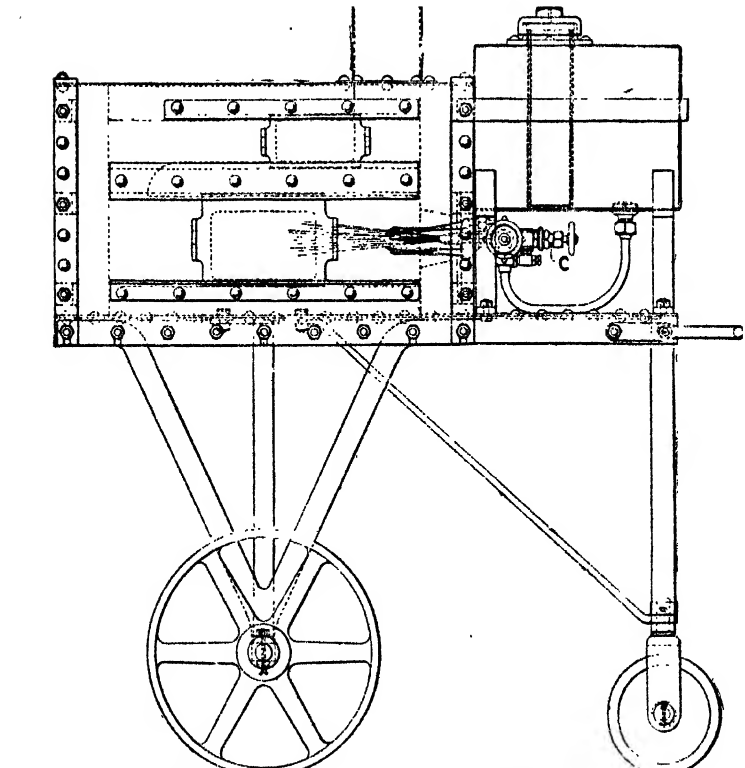


FIG. 116.—Riveting furnace arranged with Holden's system of liquid-fuel burning.

furnaces may be made of any size, but the usual capacity is about 500 lbs. to 1000 lbs. for each furnace.

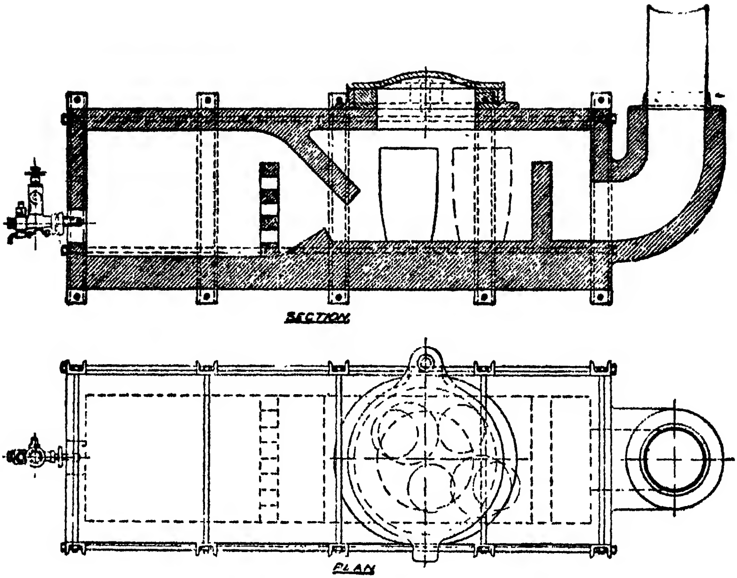


FIG. 117.—Section and plan of crucible furnace designed by Messrs Taite & Carlton.

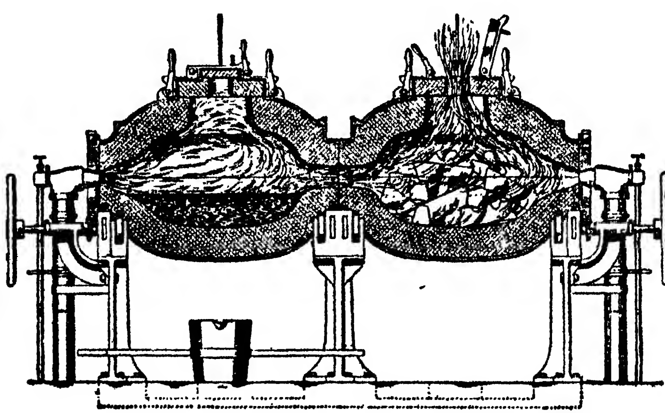


FIG. 118.—Rockwell duplex reverberatory oil furnace.

The workings of a Rockwell double furnace[1] of the larger size shows results as follows:—

Metal charged	7000 lbs.
Oil used in melting, including that used in heating up	93 gals.
Oil used per 100 lbs. of metal melted . .	1·3 gals. (U.S.A.).
Time required to heat up furnace, starting cold	27 mins.
Oil consumed in heating up	8 gals. (U.S.A.).
Actual time furnace was in blast, including heating up	7 hours 58 mins.
Time per 100 lbs. of metal made . . .	6·8 mins.
Weight of metal per minute	14·6 lbs.
Average time per heat of 500 lbs. . . .	34 mins.

In the application of oil in furnaces for forging purposes where this fuel can be obtained cheaply there is, for more reasons than one, a great gain, the experience of the Southern Pacific Railway, U.S.A.:—All the coal-heating furnaces in the rolling mill,[2] as well as the larger reverberatory furnaces used for large locomotive and marine forgings at these works, have been converted into oil-burning furnaces.

In considering the use of oil-fired furnaces, the first question is the number of gallons of crude oil required to bring one ton of scrap iron, put up in piles varying from 200 lbs. to 1000 lbs., to a welding heat. This for a rolling mill in the Sacramento shops is 40 gallons of crude oil as it comes from the well to heat 2000 lbs. of scrap material or pile. In our old coal reverberatory furnaces 500 lbs. of bituminous coal was required to heat the same quantity of metal. The next thing to be considered is the handling of the two fuels. It requires six men to bring the coal to the reverberatory furnaces and bolt factory from the coal pile. Our oil tanks are arranged so that one man distributes oil over the whole works. Another thing to be considered is the hauling away of the ashes and cinders that are produced daily, as it requires a horse and cart daily to remove this waste to the dumps. Another important consideration is the fireman, who has to handle between five and six thousand pounds of coal daily, clean his grate bars at noon and night, shovel out the ashes and cinders, and oftentimes

[1] *Proceedings Pittsburgh Foundrymen's Association*, 1905.
[2] *Proceedings National Railroad Master Blacksmiths' Association.*

knocks out the brickwork in the fire-chamber trying to knock off the clinkers. All this hard labour is reduced 75 per cent. by the use of oil.

The output of the furnaces heated with oil is at least 20 per cent. more than with coal. One reason for this is that there is no time lost in cleaning grate-bars and wheeling out ashes. But the most important question relative to the two fuels is the improvement in quality of the iron produced from the scrap material; hammered iron for railroad appliances, such as locomotive forgings, or for any other purpose where the metal is subject to compression, tensile, vibrating, and torsional strains, produced from oil fuel being much superior with oil-firing than when coal was used. Again, scrap material heated with oil develops less defect in working by lamination than iron brought to a welding heat with coal, and this shows to particular advantage with car axles, of which there have been 50 per cent. less condemned on account of seamy journals since adopting oil fuel.

Another important factor in the expense of operating is the power required to atomise the oil and furnish sufficient oxygen to produce perfect combustion. Compressed air is an expensive commodity, so is steam, and, further, the latter is not as good as compressed air for this purpose. The old fan blast is the cheapest and best when properly applied. From 8 ozs. to 10 ozs. pressure is all that is required for atomising and perfect combustion.

Success with oil-burning depends also on the shape of the interior of the furnace. In many cases the old method of providing a combustion chamber about 4 feet or 5 feet from the bridge wall—injecting the oil at one end of the furnace, causing the heated gases to pass over the bridge wall and to come in contact with the metal—is used. Openings are left in the lower portion at the end of furnace, permitting the air to be drawn in. Another method is to carry the end wall 4 or 5 feet back of the original bridge wall, and build up several courses of perforated brickwork a little above the opening made in the lower portion of the end of furnace, for the purpose of heating the extra air drawn in to obtain better combustion.

The burner passes through an aperture in the brick wall

F (fig. 119), directly over the flue, blowing the flame in over the metal. The furnace is 3 feet beneath the hearth and furnace roof, this height giving plenty of room for perfect combustion by the time it reaches the wall C. An incandescent flame then returns by the draught of the flue, as shown by the arrow points, and when mixed with the metal to be heated, the waste gases can be diverted under a boiler for producing steam, or through a stack as desired. Much care should be taken in placing the burner direct in line and about 7 inches or 8 inches below the roof, so

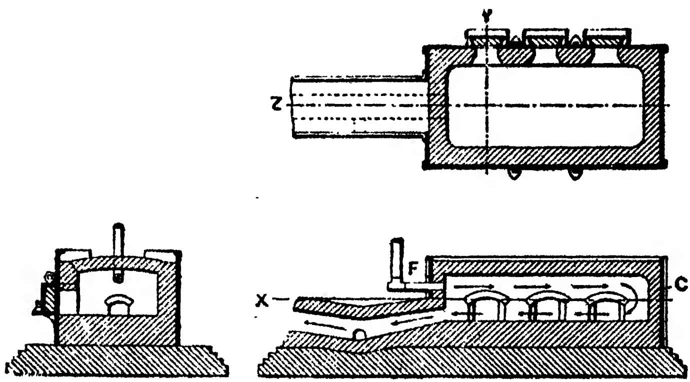


FIG. 119.—Bar-heating furnace used at Southern Pacific Railway Works.

that perfect combustion can take place before the flame comes in contact with the iron on the hearth, or the heated walls of the interior of the furnace.

The furnace shown in the illustration is that of the 3-door rolling mill type, all the forging furnaces having two doors only, operated by the same method as the 3-door furnaces. In the working of the furnaces with oil fuel perfect combustion is produced, and not a shadow of smoke can be seen from the stacks when properly manipulated.

The burner used (*vide* fig. 120) can be operated either with steam, compressed air, or with an air blast of 7 ozs. to 10 ozs. of pressure.

When steam is used the blast pipe C should be removed and a steam pipe substituted. When compressed air is

used a similar change should be made. A represents the fan blast pipe. B, regulating gate in blast pipe. C, air pipe leading from blast pipe to the outer end of burner pipe. D, gate to regulate the blast passing into the burner pipe. E, oil pipe connecting the burner pipe. F, oil and wind pipe or burner pipe. G, outlet to oil and burner pipe.

For heating crucible furnaces for melting copper, brass, tin, or steel, the Monarch Engineering Co., of Baltimore, U.S.A., use an air-jet burner having an oil nozzle controlled by a needle valve, which nozzle, being surrounded by an

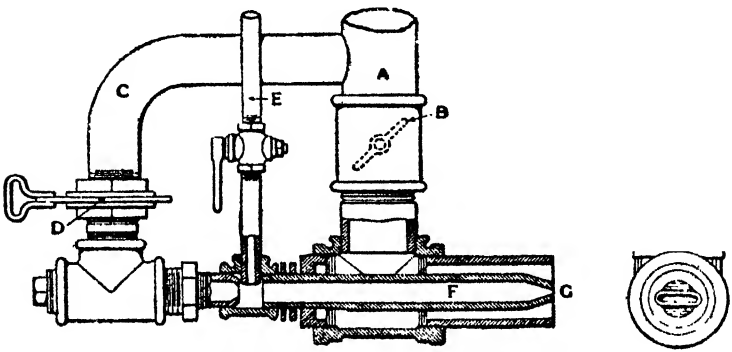


FIG. 120.—Low-pressure air-jet burner (Camp).

air chamber having a second nozzle, causes the oil steam to be thoroughly broken up by the issuing annular air jet. In applying oil fuel for purposes of the above kind, the flame is directed against a graphite block, and in turn circulates entirely around the outside of the crucible, as shown in fig. 122. As the flame does not come into direct contact with the crucible, the life of the crucible is prolonged from 20 to 50 heats. A lid placed over the crucible prevents the escape of gases, and also prevents the mixture in the crucible from oxidising. It is not necessary to remove the crucible from within the furnace when pouring, and thus cool it off, as the furnace is swung on trunnions and is easily tilted to any angle by means of the gear wheel and worm connections. This furnace is especially adapted for melting brass borings and turnings, and is

supplied in four sizes with capacities of 2400 lbs. to 4000 lbs. of metal per day. It is claimed that 100 lbs. of metal can be melted with $1\frac{1}{2}$ gallons of crude oil.[1] The illustration (fig. 121) shows the furnace in the melting and pouring positions, and also the arrangement of the plant and piping for furnishing the oil and air to the furnaces.

In the lift-out type of melting furnace illustrated by the elevation section, fig. 122, the crucible *c* rests on a graphite block *g*, on to which the flame from the burner is directed from one side in a tangential direction, and circulates around the crucible in the furnace *f*. An important feature in these very compact and conveniently arranged oil furnaces, which are supplied by the Alldays & Onions Coy., is the method adopted for lifting the cover aside.

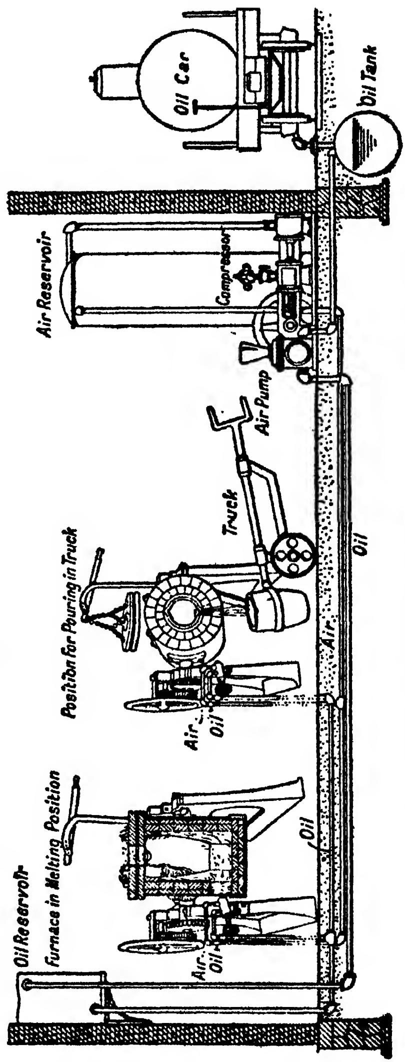


FIG. 121.—Steele-Harvey metal-melting furnace, showing arrangement of oil and air pipes.

[1] *The Mechanical Engineer.*

The cover or lid *d* is first raised an inch or so by the hand lever *l*, when it can be easily swung round on the post *p* so as to clear. The burner used is illustrated by fig. 123, from which it will be seen that air (from ½ to 3 lbs. pressure) is supplied at *a* and adjusted by turning the nozzle cap *e*, the

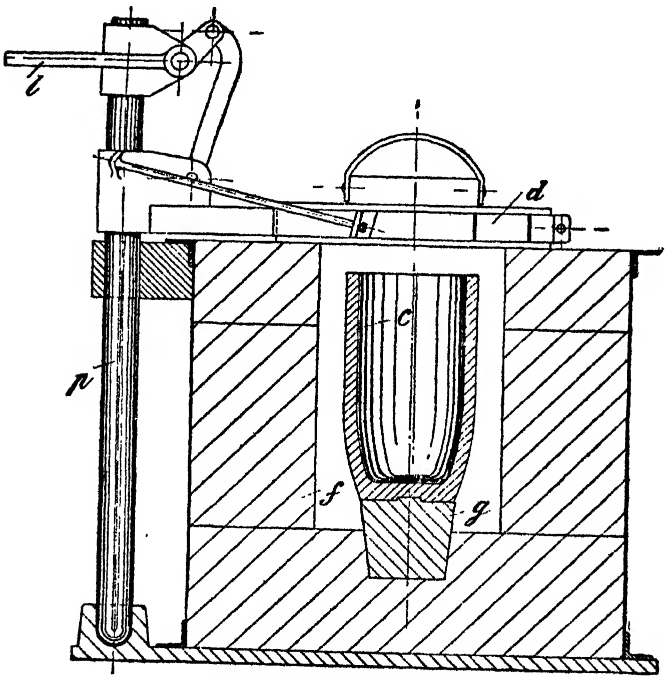


Fig. 122.—Alldays' crucible oil furnace, lift-out type.

oil entering from an overhead tank by the pipe *f* being regulated by the needle valve *n*. Alldays' burners are made in five sizes, all in gun-metal, the smallest size requiring a ⅜-inch diameter oil-supply pipe and using from ½ to 1 gallon of oil per hour, and the largest size consuming from 3 to 9 gallons per hour according to the requirements, *i.e.* whether used for hardening, forging, or melting.

Melting furnaces of this make are also made in several forms, and in addition to being adapted for solid fuel (coke), and gaseous fuel (illuminating, producer, and water gas), are constructed for liquid fuel, which may be either tar oil of specific gravity from 1 to ·9, or any of the low-grade petroleum residual oils.

Many makers specialise on different methods for convenient pouring of the molten metal. Of course the cheapest form of crucible melting furnace is constructed

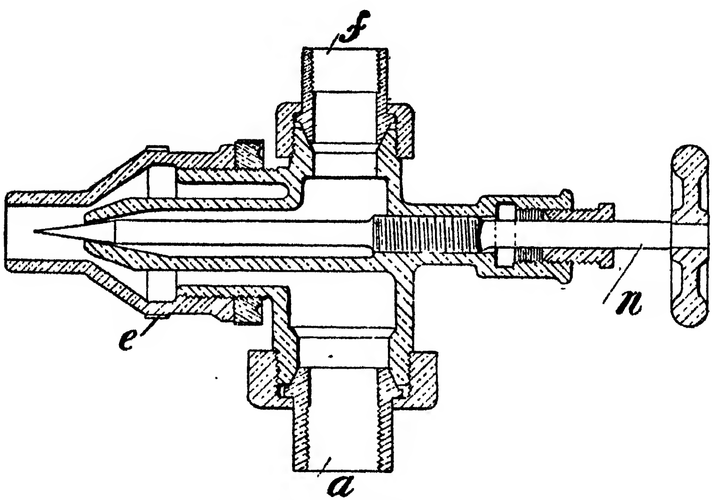


FIG. 123.—Allday's low-pressure air-jet burner.

with a *lift-out* crucible, as shown in figs. 122 and 128. Melting furnaces arranged for three or four crucibles of the lift-out type can also be heated from one burner, thus effecting a great saving in the oil consumed.

Another form of melting furnace, also of this make, is illustrated by fig. 124. This furnace (known as the "Charlier" rolling melting furnace) consists of an iron drum *d*, lined with refractory clay *l*, which is revolvable about trunnions *n*, supported by a pair of standards *t*. In this form of furnace the burner *b* is fixed at one end to blow through one of the trunnions made hollow for the

purpose; the flame is consequently blown right on to the metal and effects a certain economy by the direct contact of the flame. *It is essential, however, that the fuel used should be free from sulphur, especially in melting brass, as copper has a strong affinity for sulphurous acid.* In practice, almost any kind of oil can be used: creosote, tar oil, petroleum residuals, etc., the consumption being approximately 2 gallons of oil to melt 100 lbs. of brass, a good deal depending on the quality of the oil and the manner of handling the furnace. Turnings and borings require more oil than ordinary scrap metal.

PARTICULARS OF "CHARLIER" ROLLING MELTING FURNACE.

Approximate Time required to melt Charge of Brass.	Size Number of Furnace.	Capacity in Lbs.		
		Brass.	Aluminium.	Cast-Iron.
30 minutes . .	1	300	90	250
40–50 minutes .	2	600	270	500
50–60 „ .	3	1200	540	1000
80–90 „ .	4	2400	1000	2000

The air pressure recommended is from 10 inches to 14 inches w.g. for aluminium; 20 inches to 30 inches w.g. for brass; and from 50 inches to 60 inches w.g. for cast iron. The same type of burner is used as for the lift-out crucible furnace, the oil being fed by gravitation from a supply tank placed in any convenient position, and from 8 feet to 10 feet above the floor level.

It is claimed for this type of melting furnace, originally designed for aluminium—a purpose for which a thinner fire-brick lining may be used—that it is more economical in operation than any form of crucible furnace, owing to the direct contact of the flame; further, in being fitted with a removable plate fixed round the pouring-hole, the fire-brick lining at this point which suffers the greatest wear can readily be replaced without interfering with the rest of the lining. The shell of the furnace is constructed of heavy steel plate, and the ends formed with cast-iron discs; it is mounted on cast-iron standards having split

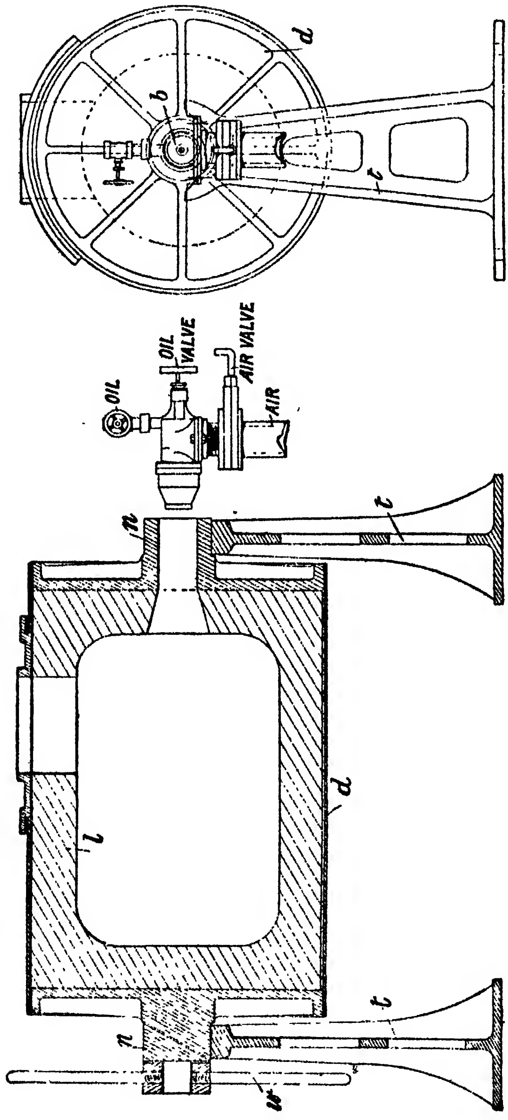


FIG. 124.—Alldays' "Charlier" rolling melting furnace.

bearings, thus allowing the drum to be picked up by a crane when desired, and enabling the metal to be poured direct into the moulds. This is a distinct advantage in many foundries. For emergency cases in the iron foundry it is also very useful, as a charge of cast-iron can be melted in a very short time.

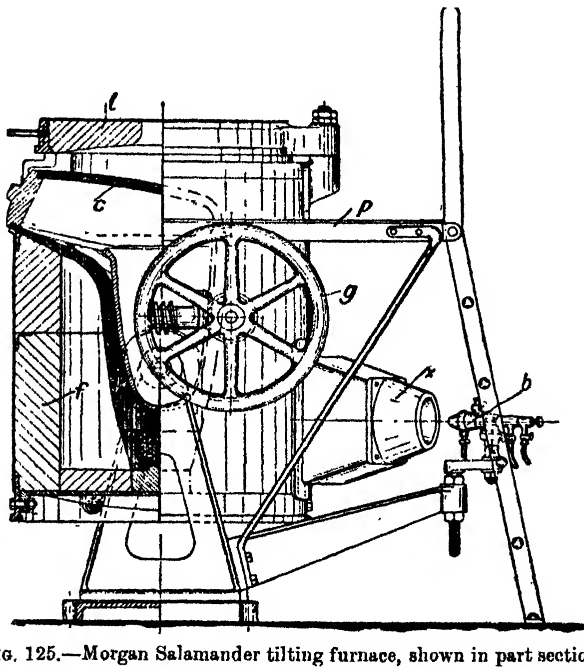


FIG. 125.—Morgan Salamander tilting furnace, shown in part section.

A third type of crucible furnace is illustrated by figs. 125 and 125A, known as Morgan tilting furnace. In this furnace, adapted for solid, gaseous, and liquid fuel, the crucible *c*, of salamander form, preserves the metal from contact with the furnace gases, which is obviously a distinct advantage when using fuel containing sulphur, and especially so with coke, and in any case there is claimed for this form of crucible a certain gain due to non-oxidisation of the metal. The "Morgan" oil burner (fig. 126) works

with a high-pressure air blast (25 to 35 lbs. per sq. in.), and as shown at *b* (fig. 125) is arranged to blow through a mixing box *x* in the form of a tuyere, and to direct the flame at a tangent to the base of the crucible, the gases escaping by an opening in the furnace cover. Crucible furnaces of this simple form are more generally used for melting yellow metal alloys, for which purpose preheating of the air

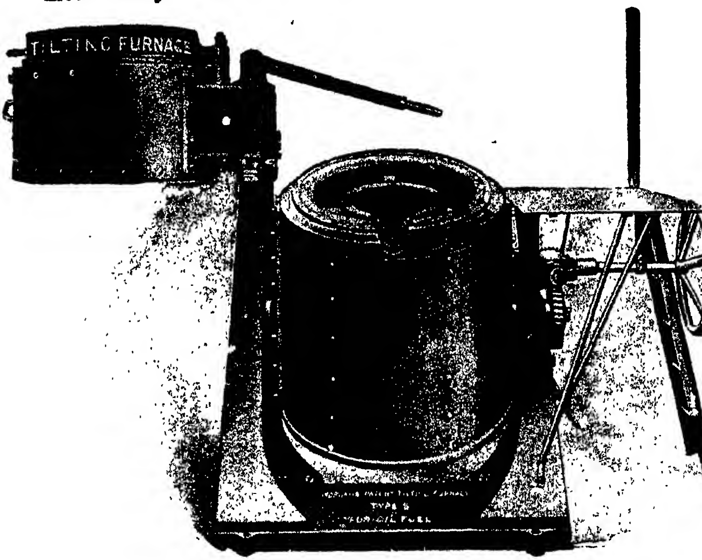


FIG. 125A.—Morgan oil-fired furnace, shown in position for pouring.

supplied for combustion is not necessary; they are, however, also made for melting cast-iron and steel, for which purposes the furnaces are constructed for the ingoing air to be heated by the escaping gases in a simple manner. The consumption of oil per 100 lbs. of brass averages about 10 lbs. as compared with 15 lbs. of coke; for melting cast-iron about double this quantity is required. The furnaces, as supplied by the Morgan Crucible Co. of Battersea, are made in several types (the example illustrated by fig. 125 being especially adapted for smelting cyanide precipitate),

and are all fitted with worm and segment pouring gear *g*, and platform *p* (fig. 125). To facilitate the tilting operation, the upper section of the furnace—known as the preheater—is lifted slightly by a cam and lever, and swung clear of the body of the furnace when a pour is to be made. The upper section—as shown in fig. 125, representing the latest model—consists of a cylindrical steel casing, lined with refractory brickwork similarly to the lower section, and is fitted with a sliding cover—for use when charging the crucible or for inspection—through which the waste gases are exhausted. When in position this preheater section makes a tight joint with the main section, and encloses the salamander muffle ring, and as this fits evenly on the top of the crucible, the

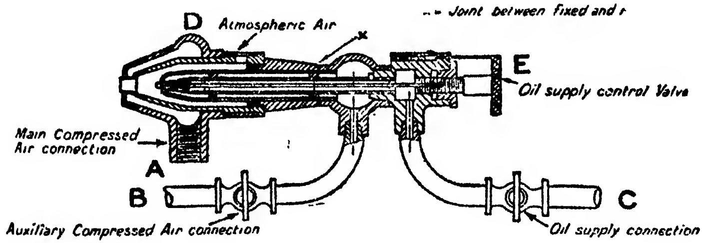


FIG. 126.—Morgan high-pressure air-jet oil-burner.

gases of combustion are prevented from passing over the metal; the supercharge of metal is also protected from contact with the flame.

The furnace body swings clear of the burner *b*, which is fixed independently and retains its position unaltered during the operation of pouring; any metal that may then run over collects in the bottom of the furnace, and can be emptied through a tap hole provided.

It will be recognised that this form of furnace is constructed on a comparatively elaborate plan, by which not only is the metal sealed to the furnace gases, but evaporation, and consequently loss of metal and temperature, prevented; to which one must add the statement that this form of crucible furnace is quite the most convenient to handle of any, and compares in this respect, in ease of

manipulation, with furnaces of the trunnion type, in that the "pour" can be controlled with the utmost nicety. In point of output, a furnace of 400 lbs. capacity (ingot) brass requires, approximately, 60 lbs. of tar oil or creosote; for 380 lbs. scrap brass, about 50 lbs.; and for 350 lbs. grey cast-iron, about 90 lbs. of fuel. The time for melting (after the first heat) ranges from 40 minutes for brass to 100 for cast-iron.

The costs per ton of metal melted are approximately 19s. with coke, and 24s. with oil, at present prices, *i.e.* 50s. and 120s. per ton respectively; the cost of crucibles is practically identical for the two systems, but the cost of labour for oil-firing is less than half that for coal.

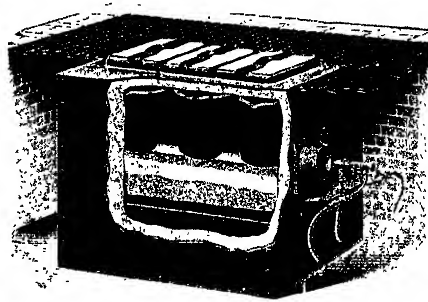


FIG. 127.—Morgan lift-out crucible furnace for oil fuel.

The efficiency and economy of the tilting form of furnace above described is chiefly due to the larger quantity of metal melted at one time, and to the avoidance of the necessity for removing the crucible from the furnace for pouring—a method which obviously leads to strain and damage to the crucible by the tongs and by changes of temperature. However, there are requirements which do not justify so large a furnace, and for these the type known as "lift-out" is sometimes more suitable; and on the Morgan system such are made either for single or multiple crucibles, and the latter either with one melting chamber or with separately controlled chambers. The type shown in fig. 127 is of special interest, for it embodies a new departure in oil-furnace construction, and is made to contain either two or three crucibles in one chamber, using only one fuel burner, or from four to six crucibles, using two fuel burners.

The multiple furnace, having one common melting chamber as shown, consists of metal sections easily put

together *in situ*, the interior formation of the refractory lining having been specially designed to obtain uniform heating by means of the burner or burners firing into the one melting chamber. The furnace is provided with a closed pit under the melting chamber, where spilt metal is collected for removal at any convenient time.

The melting chamber itself is of an oval form with elongated sides so proportioned that the flame travels equally round the crucibles, and the heat is so distributed that the metal in each crucible attains a uniform temperature.

Before being drawn away to the main flue the products of combustion are conducted through outlet ports into an external cavity, which is thus utilised as a hot-air jacket round the melting chamber. In this way the maximum efficiency is obtained from the fuel, and the furnace being entirely enclosed when in operation, no fumes are ejected into the foundry.

With regard to the form and type of burner used:—After careful investigation of alternative systems, that of spraying a low-grade thick oil by means of compressed air has been adopted as the standard practice for both the lift-out and tilting form of furnaces.

By this means the liquid fuel is completely atomised when it leaves the burner, and mixes immediately with the requisite quantity of free air, so that ignition takes place just inside the injector box; the flame expands and travels with a spiral motion round the crucible and muffle ring of the furnace, finally emerging from the central aperture in the cover, where a short yellowish flame should be visible. As the products of combustion and fume from the metal emerge from a relatively small outlet in the furnace cover they can be entirely collected and carried outside the foundry by a light telescopic chimney.

It is only necessary to supply under pressure a portion—amounting to about one-fourth, or at the most one-third of the total air required. For ordinary brass foundry use, a pressure of about 20 to 25 lbs. per square inch (1·4 to 1·75 kilos. per $cm.^2$) is recommended, but for high steel or nickel temperatures this should be increased to 30 or 35 lbs. per square inch (2·1 to 2·5 kilos. per $cm.^2$).

The compressed-air-jet burner shown in fig. 126 is of special design and formed in two sections; the rear section introduces the oil and makes a sliding fit concentrically with the front, and can be entirely removed for inspection and replaced without delay.

As will be seen, the Morgan is a double-jet burner, the main supply entering at A, and auxiliary supply at B; the oil enters at C, and issues from a central nozzle controlled by a needle valve E; between the two compressed-air jets there is an induced supply of air from D. These burners, which work very satisfactorily with the lowest grades of petroleum residues or fuel oils, tar oil, or creosote, are made in three sizes, and of the following capacities :—

Small burner—3–4 gallons (13½–18 litres) of liquid fuel per hour, 30–40 cubic feet (·85–1·1 metres^3) of air per minute.
Medium burner—4–6 gallons (18–27 litres) of liquid fuel per hour, 40–50 cubic feet (1·1–1·4 metres^3) of air per minute.
Large burner—6–10 gallons (27–45 litres) of liquid fuel per hour, 50–75 cubic feet (1·4–2·1 metres^3) of air per minute.

The burner used by the Brett's Patent Lifter Co., Coventry, differs from any other in the method adopted for mixing the air with the oil, their endeavour being to construct a burner for furnace work in which smokeless combustion can be obtained with the heaviest grades of creosote and other fuel oils with a low-pressure air blast, such as used for the ordinary smith's forge. Referring to the diagrammatic section (fig. 128), it will be seen that the oil enters by the pipe *p* by gravitation to the burner nozzle, where it is regulated by a diffusing valve in such manner as to cause the oil to be sprayed out in the form of a vertical film into the contracted end of the mixing chamber *x*, where it is met and carried forward by a hot blast of air from the jacket *b* surrounding the combustion chamber *n*, and thence into the furnace *f*. The blast is controlled by a shutter valve *v*, and the oil by the wheel *r*, by which means the valve at the end of the nozzle can be moved endways, its stem being screwed into the gland nut *g*. In the Brett's burner, in addition to superheating the air, the blast is caused to rotate a small screw-bladed cutter wheel *t*, causing the spray to be thoroughly diffused with a low-pressure head on the oil feed.

A separate fire-brick lined cylindrical combustion chamber is also used in the Höveler heating and melting furnace, the object, as in the oil-burning system just described, being to obtain complete combustion outside the furnace, and by the exclusion of unnecessary air to prevent oxidation of the metal. The oil is atomised in a double air-jet burner, as shown in fig. 126, which is fixed an inch or so outside the smaller end of a tapering cylindrical

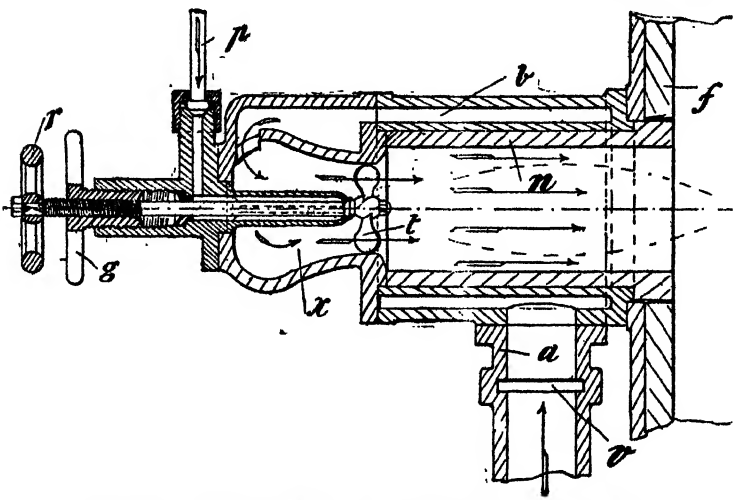


FIG. 128.—Brett's furnace fuel-oil burner fitted with preheating chamber and fan atomiser.

ignition or combustion chamber, suspended in line with the mouth of the furnace, as shown in fig. 129. In the working of the burner, which is in many respects similar to that shown in fig. 126, a double air jet of the comparatively high pressure of 15 to 20 lbs. is used; air for the primary or atomising jet is supplied at B, the oil entering at C from an open tank, which may be placed at any suitable distance, so long as high enough—about 21 inches—for the oil to flow into the inner spraying tube, whence the feed is controlled by the needle valve E. The necessary air for complete oxidation of the fuel is supplied

at A and D, both of which are under control; only sufficient compressed air to A and atmospheric air to D are supplied to produce combustion in the outer ignition chamber.

The following instructions for setting the Höveler oil-burning apparatus to work will be found useful:—

FIG. 129.—General view of the Höveler oil-burning apparatus for furnace heating.

To obtain the best results the burner must be about 1 inch distant from the combustion chamber.

To set in operation, first open the air supply B to atomiser full, and then slowly turn on the oil by turning the milled thumb-screw which operates the needle valve.

Then place a lighted piece of oily waste in front of the ignition chamber.

Gradually increase the oil supply as the igniter gets hot, and withdraw waste when the ignition chamber is

sufficiently hot to ignite and keep burning the spray injected by the atomiser.

Turn on the main air supply as soon as the flame gets smoky, and increase both oil and air as required.

Then after a few minutes' working with the compressed air and oil feeds full on, shut off the main air supply until the flame gets smoky.

The burner will then be working at its full capacity with a reducing flame.

If now the main air is again turned on it will become oxidising.

If the burner is not intended to work at its full capacity, the supply of free air must be shut off, otherwise the ignition chamber will get cold inside and a deposit of oil will form.

By regulating the supply of free air the fire can be kept inside the combustion chamber, and produces the most economic effect.

The advantage of this system is that it can be applied to any form of heating or melting furnace without requiring any structural change; the apparatus can also be very quickly got ready for work, as from turning on the oil and air supply till the production of a working flame is only a matter of a minute or so.

In the well-known Ferguson oil-fired annealing, melting, and forging, etc., furnaces, of which there is a full line of over thirty different sizes and varieties supplied by Furnaces Ltd., Westminster, a low-pressure double-air-jet burner is combined within a combustion chamber, and special flues contained within a fire-brick lined cast-iron structure of heavy and practical form to suit any particular purpose required, the aim being to obtain as perfect combustion as practicable with a minimum volume of air.

According to the Ferguson system, illustrated by three elevation and plan sections, fig. 130, a double blast of air consisting of a primary and secondary jet is used in combination with an oil pressure of 8 or 10 lbs., which is sprayed from a nozzle *n* in an upward direction and mixes with air supplied along the pipe *a* from a fan or rotary blower at about 8 ozs. pressure. The air supply is regulated by a valve *v*, and the oil along the pipe *p* by a

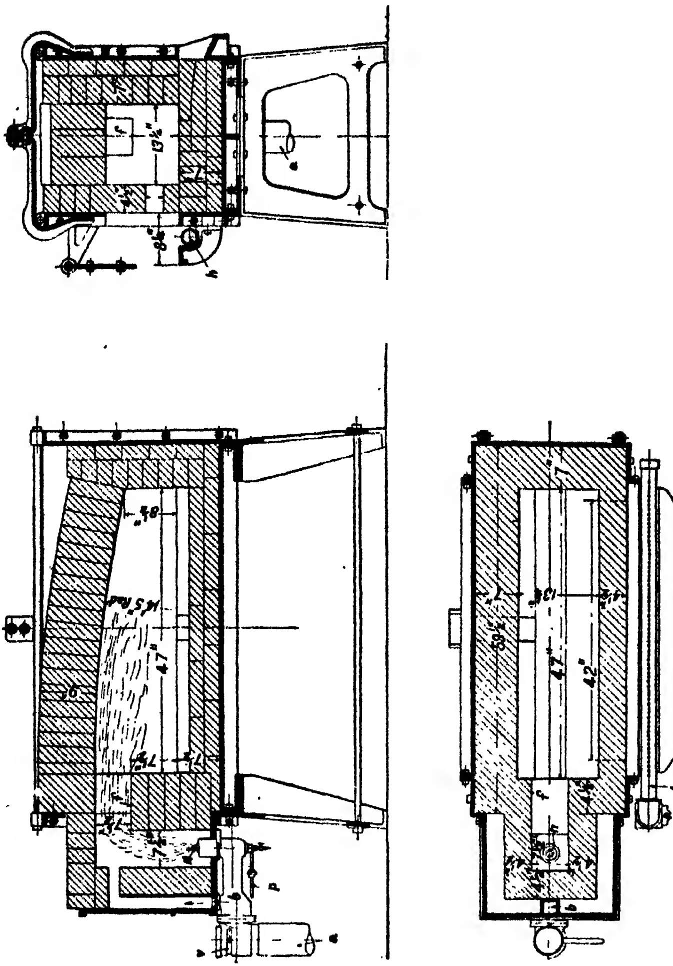


FIG. 130.—Sectional elevations and plan of Ferguson oil-fired forging furnace.

needle valve, the air jet surrounding the oil jet in the usual way carries it up along the square combustion chamber over the nozzle until it meets a cross current of air from *b*, when the mixture, which has been thoroughly atomised by the nozzle *n*, is completely oxidised and carried forward into the furnace.

Fuel oil can also be profitably applied for heating, annealing, and hardening furnaces, a full line for which purposes are supplied in connection with the Alldays burner, illustrated in fig. 123, and consist of a muffle or oven with detachable sides, which are lined with a specially durable quality of fire-brick; the burner (or burners, according to the size of the furnace) project the flames beneath a fire-brick slab, thereby forming a combustion chamber. The flame circulates up around the sides of the muffle, then reverberates from the top, and so envelops the muffle in a uniform non-oxidising flow of gases having a temperature as high as 2200° F., or 1200° C., when the burner is supplied with cold air (2 to 3 lbs. pressure); but by preheating the blast air to a high temperature by means of the waste gases, a considerable economy is obtained both in the time required for heating up the furnace and in the consumption of fuel, by which means, moreover, the furnace temperature can be raised to 2600° F.—*i.e.* over 1400° C.; and as the larger series of these furnaces have a heating capacity of 36″ × 36″ × 16″, they are adapted for heating tyres, railway carriage springs, and a number of other component parts used in general engineering work.

Another very convenient adaptation oil firing is that used on a portable form of furnace, known as the Empire, for heating rivets. This, illustrated by the photo-view, fig. 131, is mounted on legs with oil tank complete, and fitted with double doors at each end. A furnace of this type will heat 200 three-quarter inch rivets in one hour on a consumption of 6 to 7 pints of oil, and a larger size 500 to 600 one-inch rivets on a consumption of 3 gallons of oil in the hour.

In addition to the several oil-fired annealing, muffle, and hardening furnaces described, there are others, including: the Bickford, Burdon, Brüder-Boye, Davis, Gordon-Smith, Incandescent, Massey, Wincott, etc., each of which is

differentiated by some detail of an interesting character, the outcome, for the most part, of some more specialised application.

From what has already been said it will be seen that for

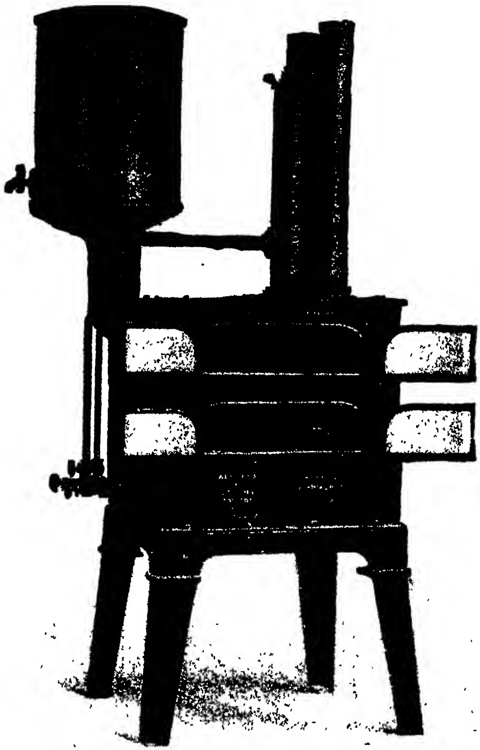


FIG. 131.—Empire oil-fired rivet-heating furnace.

metallurgical work liquid fuel is particularly suitable, and, while it has not received the attention in this country which it deserves, it has been adopted to a considerable extent in countries which, up till now, have been more conveniently situated to the producing oil-fields; as a case

in point, in one large reverberatory furnace for copper ore built by the Arizona Smelting Company, a charge of 300/350 tons can be smelted each 24 hours, and, while it is possible to deal with such a mass of ore at one operation, it is also possible to deal with extremely small quantities. In the reduction of many ores absolute control of temperature is essential, and with oil fuel this can be obtained within the greatest range of temperature of all fuels. Then again there are poor ores which, if treated in a coal-fired furnace, would scarcely pay for the fuel and labour expended, but if treated with liquid fuel as a substitute would, undoubtedly, give a satisfactory return.

For melting grey-iron in quantities of 1200–1500 lbs. or brass in larger amounts, an oil-fired revolving furnace such as the Siegen has the advantage of being self-contained and particularly easy to manipulate. Referring to the illustration, fig. 132: this furnace will be seen to resemble in some respects the "Charlier" shown in fig. 124, but differs in the controlling gear and adaptability for comparatively large "pours," besides being fitted with fuel tank, filling pump, and an effective cowl. The revolving furnace *a*, which is provided with an inner casing of fire-brick, turns at one end upon rollers *d*, carried by a bracket *e*, the control being effected by a rack and hand-wheel *f*. The air-jet burner *h* is fed with oil by natural fall from the tank *i*, and blast from an ordinary blower at a pressure of 20 inches of water column for brass, and 28–32 inches for cast-iron and steel. Before charging, the furnace is heated for a quarter of an hour, and while melting should be turned 70°–90° each way, every 10 minutes or so, to equalise the heating effect. The durability of the inner refractory casing is said to be equal to 40–50 tons for brass, 10–15 tons for cast-iron, and 5–10 tons for melting steel. The consumption of fuel, which may be coal-tar oil, averages from 8–10 per cent. in weight of the melt in brass, and 20–25 per cent. of the melt in grey-iron.

The uses to which oil is being applied as fuel[1] are steadily increasing, and one of the most important adaptations of this is to be seen in the Stock steel converter. Although this appliance is of comparatively recent origin,

[1] *The Engineer.*

it has long since passed the experimental stage, and one of these converters, with a capacity of 3 tons, was in regular service at the works of the Darlington Forge Company so

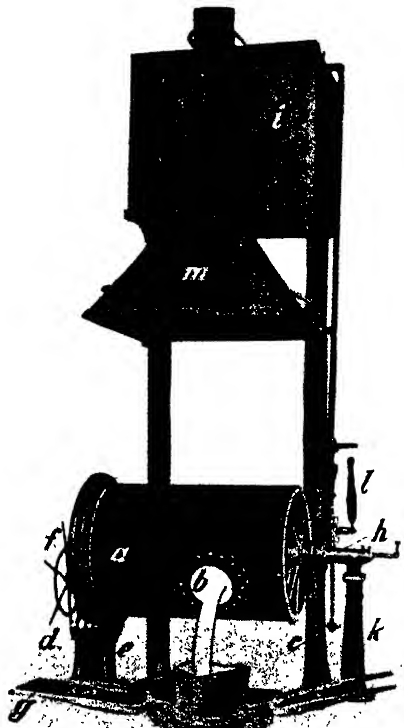


FIG. 132.—Siegen oil-fired rotary melting furnace.

long ago as 1910, where it has given most favourable results. This type of converter has been specially designed for the production of all kinds of steel, from soft steel castings to steels of the highest grades. The converter is made of oval section to enable the largest surface of the metal under treatment that is practically feasible to be

exposed to the action of the oil burners, and the tuyere-box is designed accordingly. The metal container is lined with silica fire-brick of 13 inches maximum thickness around the tuyeres, and may be used, not only for the conversion or blowing of iron, but also for melting the actual charge of iron and scrap by means of oil fuel, thereby doing away with a cupola. The converter is mounted on trunnions working in roller bearings, and is also carried on a table on which it can revolve in the horizontal plane. In fig. 133 is shown in elevation and plan the general arrangement of a typical installation. The process of charging is effected by an ordinary peel, and by this means 3 tons of pig-iron and scrap can easily be fed into the converter by three men in about ten minutes. When charged the converter is moved horizontally through an angle of 90° for melting, in which case the nose of the vessel is pointing towards the air heater. This heater comprises a nest of U-shaped cast-iron pipes provided with vertical inner ribs contained in a masonry structure lined with fire-bricks. Into these pipes cold air is delivered from a rotary blower, and after passing through the pipes is discharged at a temperature of about 800° F., and a pressure of about ¾ lb. per square inch, through a central pipe into the converter, where it is caused to mix intimately with the jets of oil and produce a highly efficient system of combustion. For blowing, the blast is supplied by the same blower that supplies the air for melting, but in this case the air pressure may vary between 2½ lbs. and 3½ lbs. per square inch.

The oil used for fuel may be of any crude variety, and is stored in a tank, from which it is forced by any suitable means into a smaller tank containing enough for, say, five or six meltings. The latter tank is fitted with a coil through which hot air or steam circulates to reduce the viscosity of the oil. It is also provided with a small independently driven compressor, which will maintain a constant pressure of from 30 lbs. to 40 lbs. per square inch, and force the necessary quantity of oil through a flexible pipe to the oil-burner tubes, which are inserted into the tuyere-box. These tubes are of steel, with an internal diameter of $\frac{1}{16}$ inch. They are secured to a suitable carrying

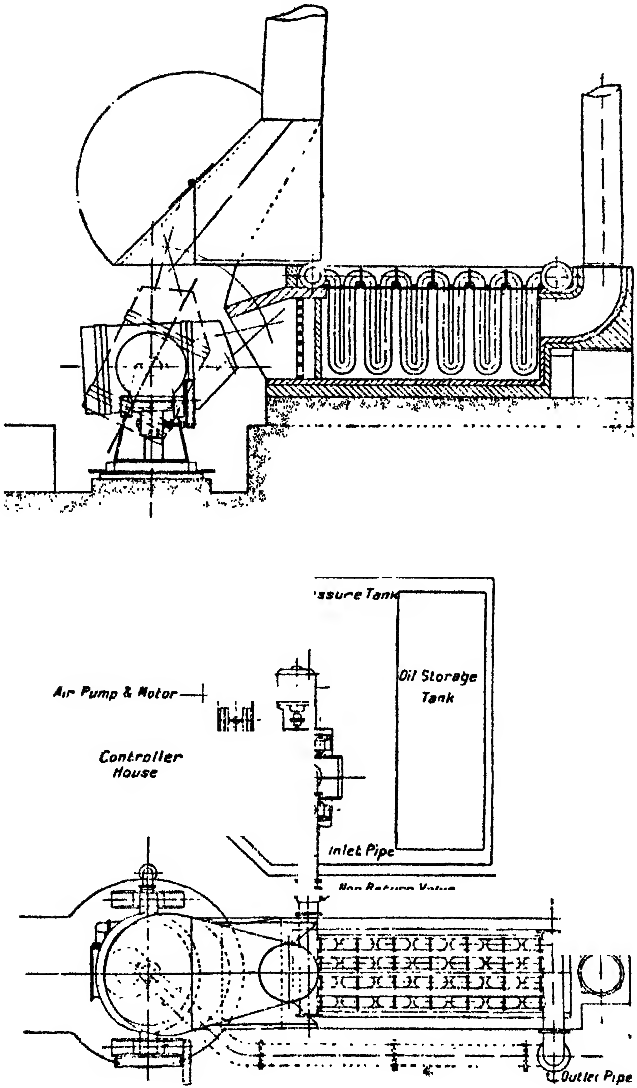


FIG. 133.—Elevation and plan arrangement of 3-ton Stock converter.

device which can be readily clamped on to the tuyere-box and removed again when the melting operation is completed. When the blowing operation is in action, as in steel-making, the oil supply is cut off, and the converter is tipped upwards, the fumes being carried away by means of a hood and chimney fixed directly above the air heater. The blowing process lasts about twenty minutes, and the converter is then turned down to the charging position, and the necessary ingredients, such as ferro-silicon or ferro-manganese, introduced. The vessel is then turned round into the teeming position and the contents are discharged.

The duration of the process from charging to teeming is from one and a half to two hours. The larger size converters are provided with electric motors (*vide* fig. 134) for tipping and turning, but for smaller sizes of converters these operations may be performed by hand.

The chief advantages claimed for this system are:—No cupola plant is required for melting; as liquid fuel is used after once the converter has been started, the steel is free from impurities such as sulphur; cupola losses and costs of melting are saved; the high temperature of the melted charge enables the use of pig-iron low in silicon or the use of higher percentages of scrap; the metal being in an extremely fluid state, the most intricate castings free from blow-holes can be produced; the amount of space occupied is small; and the power required is comparatively small.

In practice it has been found possible to obtain from 25 to 30 heats before the lining requires renewal. A charge of 2½ tons can be melted and converted in 1¾ hours with a fuel consumption of 70 gallons, and a power consumption of rather less than 50 kw.

From the foregoing it will be gathered that an oil-fired furnace is particularly useful when quantities of metal have to be melted at *intermittent periods*, as the waste of fuel and heat is reduced to a minimum. One manufacture which has, perhaps, been more considerably affected by the use of liquid fuel than any other is that of steel castings, the same advantage applying in this instance if the furnace is only required at irregular periods, and, further, the original cost of fitting up such a plant is obviously con-

siderably less than a plant for gas fuel; also, the quality of the steel obtained is much improved.

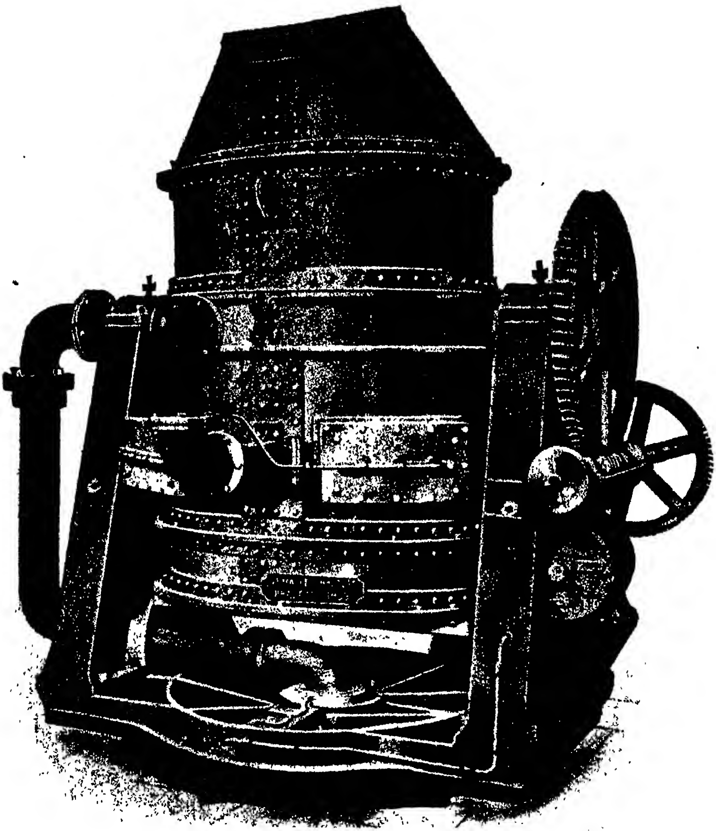


FIG. 134.—Elevation of 3-ton Stock converter, shown in blowing position.

The freedom from sulphur in the gases formed by the combustion of most of the fuel oils is a very important

advantage, and, apart from the economy gained, renders a particular value to its use for the many processes wherewith an accurately graded and even temperature, together with a non-oxidising flame, is a *sine qua non.* Probably the glass trade have taken greater advantage of this property than any other, as it has been adopted in several factories with highly satisfactory results. At the Curle glass works, South Hackney, for instance, liquid fuel has been used for many years. There, the furnaces work at a temperature of from 2300° to 2500° F., and in proof of the complete combustion obtained and the purity of the pro-

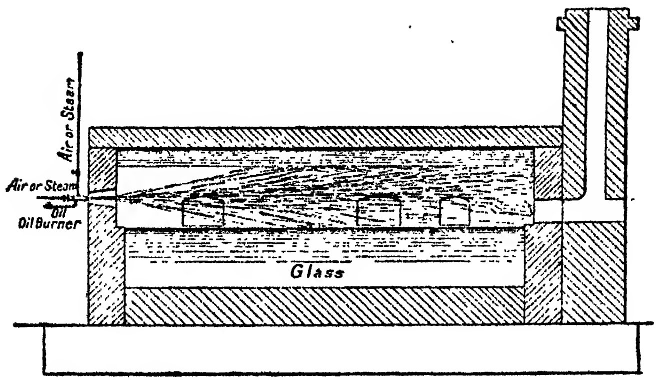


FIG. 135.—Six-ton open-hearth glass furnace and arrangement of Carbogen fuel-oil burners.

ducts, white flint glass is melted in an open tank furnace, the flame being in actual contact with the metal without any discoloration or deterioration of the glass produced. This, as all glass manufacturers will understand, greatly reduces the quantity of fuel necessary as against the old method of melting white flint glass in crucibles.

"In the manufacture of all glass or china articles many pieces are ruined by incorrect firing, whether coke or coal is used, and both time and labour are expended upon material which is bound to be condemned. A slight modification in the design of the oven renders the adoption of liquid fuel possible, as will be seen by an examination of the sectional cut, fig. 135, illustrating a 6-ton open-

hearth glass-melting furnace arranged to be heated by a pair of Carbogen oil burners, which are alone capable of melting and maintaining in a molten state a bed of glass weighing from 6 to 7 tons and some 18 inches deep, on a consumption of from 6 to 8 gallons of fuel oil. The chief interest, however, lies in the burner (*vide* fig. 136), which, although particularly adapted for this purpose, is also suitable for steam raising, a strong point in its favour being the ease with which flame can be produced, as with everything cold, the burner can be lighted at once with a small piece of paper. The fuel is atomised by a double air jet, which issues both inside and outside the oil jet. After the burner has been at work for a short time the air can be shut off and steam turned on in its place. This is a

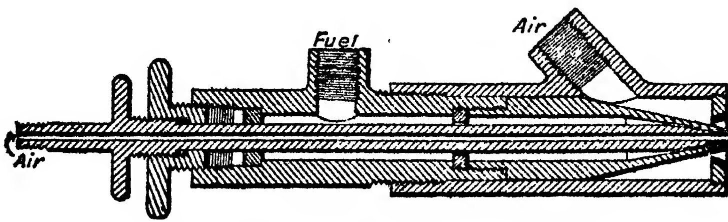


FIG. 136.—Carbogen double air-jet burner (Stackard).

valuable feature, the idea being that a small jet of compressed air should be only used for starting, and that as soon as sufficient steam pressure is generated—9 lbs. to 10 lbs.—the burner can then be turned over to steam; when it could either continue to work in that way, or sufficient steam having been generated to get the engine under way, it may drive a small air compressor to supply the burner.

"It is instructive to notice the difference in the flame under the two conditions, the jet appearing to be longer and narrower and the flame far more active when compressed air is used than when steam is turned on, and there appears to be no doubt that the temperature in the former case is higher than in the latter. In neither case is any visible vapour produced, or any smell detected. Two sizes of burner are used at these glass works. Those of the larger size consume $3\frac{1}{2}$ gallons per hour each, and the

smaller burners ¾ gallon per hour each. The volume of air through the larger is about 25 cubic feet, and through the smaller about 10 cubic feet per minute at a pressure of 18 lbs., which is only necessary where a high localised heat is required. One compressor driven by a 15-h.p. electric motor runs six large and five small burners, consuming in the aggregate from 20 gallons to 30 gallons per hour. The burners themselves are quite small things, the larger measuring only 10 inches over all by 1¾ inches diameter, and the smaller 5 inches over all by 1¼ inches diameter. The point to be observed is that the compressed air issues in the form of a double set. It flows right through the small central orifice and effects atomisation, and this is rendered more complete by the outer annular jet also issuing at the point of efflux of the spray. A careful adjustment is necessary, but once effected it is permanent. The burner can be regulated down to about one-quarter of its normal consumption by the movement of the inner tube, which is actuated by a differential screw, as shown. The air enters the burner under a pressure of from 9 lbs. to 14 lbs., and the oil flows in by gravity. Atomisation and combustion appear to be complete; there is no clogging or carbonisation of the burner; and no part of it is subject to wear, which is important, as they are required to be in continuous action week in week out for twenty-four hours a day."

This freedom from clogging or carbonisation is a very great feature, and is the inherent fault of so many similar appliances. These burners have run for as long as eighteen months continuously without in any way blocking up or having to be cleaned. The fact that about 25 tons of liquid fuel per week is consumed, with *absolutely no smoke*, is, in itself, a practical testimonial not only to this particular form of burner, but also of the advantages of liquid fuel for this purpose.

The method of applying the burner to a glass furnace is quite simple, and it will be noticed that the flame is injected through a divergent opening in the furnace wall (*vide* fig. 135). This tapers from about 4 inches square to 8 inches on the inside, thus giving a clear entrance for the atomised admixture.

No heating of the fuel, however viscous, is necessary, as where a particularly dense fuel is used a slight air pressure on the supply tank will at all times ensure a constant and

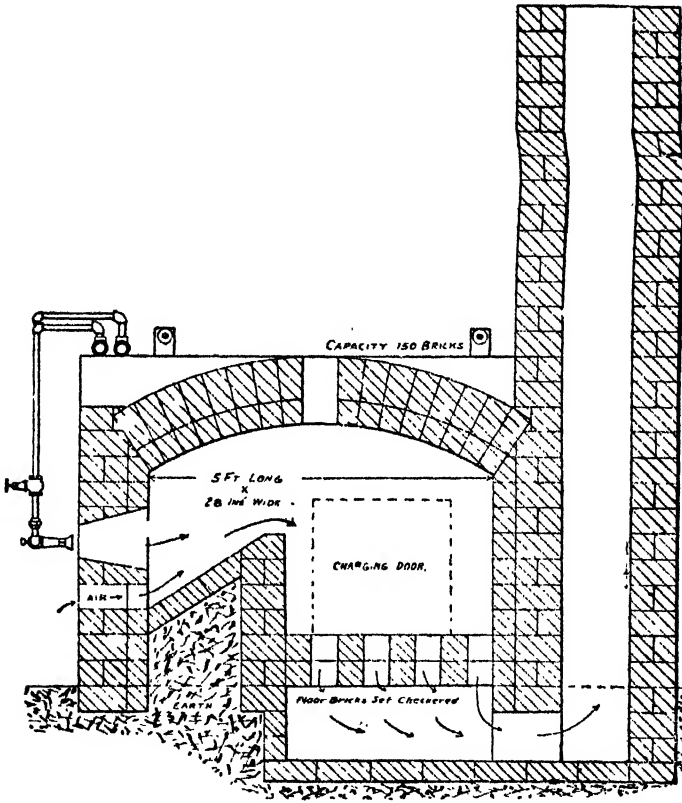


FIG. 137.—Section of oil-fired furnace for brick kiln.

steady flow. The method of lighting up is quite simple:—First, the air valve leading to the central supply is slightly opened; a lighted torch of oily waste is then introduced into the combustion chamber, after which the fuel valve is gradually turned on, and finally the outer air supply is

started. All three valves are then regulated until the required flame is produced, after which the burner continues automatically without further attention.

The application shown in fig. 137 is probably more extensively adopted in America than elsewhere, for the reason that there, and especially in the western States, oil compares to more advantage in point of cost. So well, indeed, is this recognised for kiln work of all kinds out there, that it is quite common to find a single brick, tile, or pipe kiln with from 20 to 50 furnaces, all fired with oil. The advantages of oil—where the price does not exceed three times that of coal or wood—when used for burning clay and light-coloured brick and tile ware, consist in producing a much more even colouring with practically no deterioration from smoke, soot, or uneven heat. Again, for glazing brick or tile ware, oil furnaces are much more convenient, easily regulated, and uniform in temperature. For this purpose both steam- and air-jet burners are used, but with steam when in long lines, some difficulty results from condensation, and to avoid this the Schurs double atomiser burner shown in Chapter VI., fig. 24, was primarily devised, and still continues to be the best known for this work. This burner is in part a mechanical atomiser, the oil being fed to it at a pressure of 30 lbs., and the air at an equal or higher pressure; or if steam, this should be dry, and at not less than 50–60 lbs., and the oil at just sufficient head to overcome viscosity; air atomising is more generally adopted for kilns having down-draught furnaces, as shown in the illustration, and steam for up-draught kilns.

CHAPTER XIII.

OIL FUEL FOR LIGHTING AND DOMESTIC PURPOSES.

The employment of liquid fuel for domestic purposes has up to the present time received comparatively little attention, for the reasons that the price of oil prohibits its use excepting on a small scale, and that popular prejudice is against the displacement of a fuel which has become recognised as an indispensable part of domestic life. There is a simplicity about the matter of putting a shovelful of coal on the fire, and is preferred by many to gas, while the use of oil fuel would entail another set of conditions, and unless of great economic advantage would not appeal to the ordinary householder.

The only countries in which any attempt has been made to introduce liquid fuel for heating purposes in the home have been America and Russia, where the supply of oil is cheap and readily obtainable. Even there, however, the application is not at all on a large scale, and there is an aversion to its use on account of erroneous ideas that it is impossible to burn it properly in ordinary stoves, and that it will give off smoke and soot, and entail dangers not present in the use of coal. So settled has been this conviction in Russia that even the municipal authorities of such towns as Baku, Tiflis, and Petrovsk, etc., have been constrained at one time and another to issue strict injunctions prohibiting its use in dwelling-houses.

It is rarely possible to adapt existing stoves to petroleum burning, for the reason that the firing chamber and flues have to be specially adapted for oil fuel and are of as great importance for complete combustion as the form of

the burner itself. It is true the stove introduced by Baskkoff some years ago for house warming and culinary purposes gave a soot formation of only 0·0003 per cent. of the total amount of fuel used (and without the aid of atomisation), and for this he was awarded the gold medal of the Imperial Russian Technical Society; there were also prizes awarded for oil-burning apparatus adapted for domestic heating and lighting purposes, at an industrial exhibition held at Petrograd just before the war.

The domestic purposes wherewith a practical and simple form of heating lamp can be applied are very various. The objection to oil lamps having wick burners is only too well known, owing to the next to impossibility of obtaining perfect combustion, and, as a natural consequence, when used in an unventilated room, the acrid vapours arising therefrom are alike pernicious to animal and vegetable life. Then, again, there is an objection to the ordinary form of vapour-jet burner heating lamp, owing to the frequent choking of the nipple, this in all blow-lamps having but an extremely small aperture, which calls for much care and some skill to clear. The vaporiser, too, of the ordinary lamp of this kind is prone to get choked with a solid deposit thrown down from the oil, if not of a suitable brand, and as the vaporiser is usually constructed in one piece, either in the form of a hollow ring, coil, or combination of the two, when once thoroughly clogged up it is obviously difficult to clear.

In this connection great interest attaches to the Tacchella oil-burning device shown in fig. 138, in that it is adapted for low-grade oils, and is the only form of atomiser burning apparatus yet devised for domestic use. There is here seen a most ingenious combination of steam generator, steam-jet burner, and automatically controlled oil and water supply, all of which parts are mounted on one frame of circular form with lugs, by which the device may be attached to the door of a stove, hot-water boiler, baking oven, or other heating apparatus.

The burner consists of a steam jet and an oil jet, the former having a needle valve which is the only control on the apparatus. The two jets meet at an angle of about 45°, the steam under a pressure of 10 lbs. causing the oil

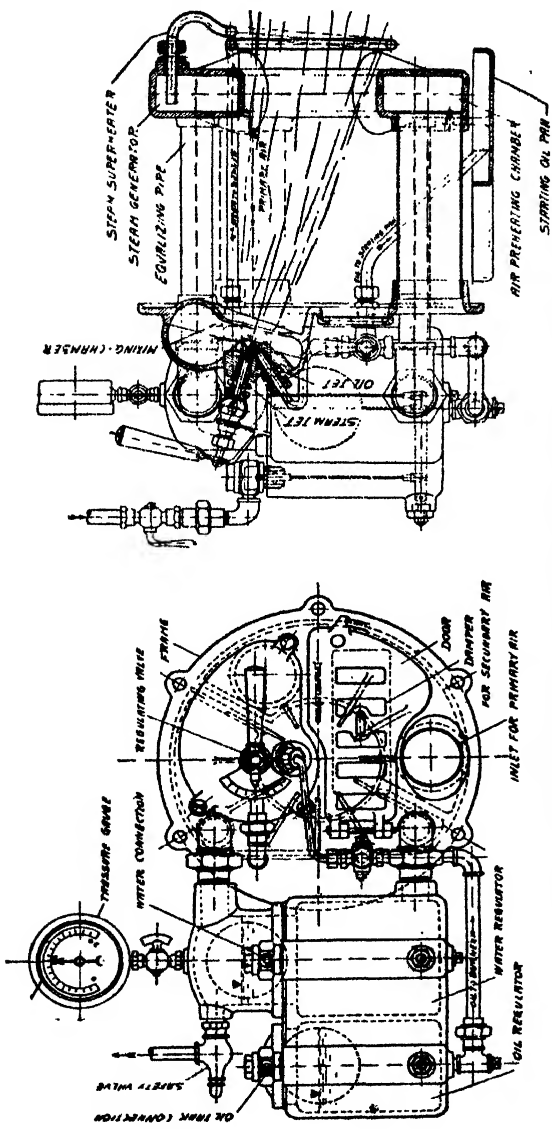


FIG. 138. —Tacchella oil-burning apparatus for general heating and domestic use.

to issue by induction. The oil and water chambers are arranged so that the oil is heated by the hot water. Both chambers are fitted with float-regulators for maintaining the oil and water at constant levels as shown, that for the water being connected with the annular steam generator. Steam for the atomising jet is superheated by a coil in the path of the flame, in addition to which the combustion chamber is supplied with pre-heated air. Starting occupies 4 to 5 minutes, and for this a tray is provided having a capacity of half a gallon of free burning oil. This useful apparatus, which is fitted with a pressure gauge and safety valve, is made in two sizes, one having an outer frame-diameter of 12 inches, and weighing ½ cwt., consuming 1·5 to 2 gallons per hour; while the smaller heater, with a diameter of 9 inches, consumes 0·75 to 1 gallon per hour, and for its size is truly the most remarkable example of the application of the atomiser principle.

However, blow-lamps are extremely useful for a variety of purposes, such as soldering, melting tin, blistering paint, and for general domestic and other purposes, wherewith it is an advantage to be able to quickly obtain a heat of high intensity and with but little trouble. The form of burner most generally used consists of a double loop depending at right angles (fig. 139) from a tubular ring *v*, one of these tubular loops being brazed to the connection for the oil container, and the other used to carry the vapour nipple *b*. A dished tray *p* is provided for holding a little methylated spirit to be used to heat the vaporiser before turning on the paraffin.

In order to remedy in part the liability of blow-lamps from choking, the writer, some years ago, devised a vapour burner (*vide* fig. 140), in which the vaporiser *n* was constructed in the form of an annular conoidal-shaped box having a removable cover *l* for cleaning. A burner with this improvement, however, after a prolonged use (extending to some 100 hours), such as when kept continuously alight in maintaining the vaporiser of an oil engine at an even temperature, was sooner or later found to give trouble from clogging of the burner nipple, although the space between the sides of the vaporiser was packed with gauze and the best brands of kerosene or paraffin oil were used.

An effectual remedy for this difficulty was eventually found to consist in placing a renewable core of filtering substance, as at *f*, in the path of the vapour; silicate of cotton or asbestos answering the purpose equally well.

Owing to the extremely small outlet for the vapour and the very delicate clearing prod necessitated for opening the nipple nozzle to its full extent, and the next to impossibility of effecting this while the burner is alight owing to the fusing of the wire used for this purpose, some difficulty was still experienced; this fault, however, was to a great extent obviated by the use of a burner having an adjustable feed, as illustrated in fig. 141. In this blow-lamp, which is shown adapted for ordinary purposes, the same form of vaporiser *n* and filtering plug *f* were used; but the burner *b* was provided with an inverted pin valve *p*, having a finely tapering end, by which, and the thumb-nut provided, the intensity of the flame could be nicely adjusted to suit any ordinary requirements; a regulator of this kind is also useful for clearing the burner when showing signs of choking. As in all successful burners of this type, the vapour jet strikes against a deflector, and in this case consists of three hollow ribs *e*.

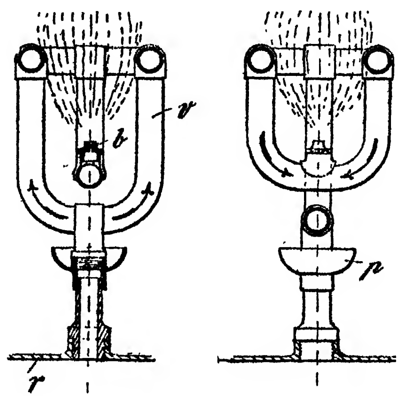


FIG. 139.—Vapour burner used in the Primus, Vulcan, etc., class of blow-lamps for heating purposes.

The *modus operandi* for a vapour-jet burner is usually to first heat the vaporiser by a little methylated spirit for a minute or two, or the same effect (if in the open) can be obtained by lighting a piece of cotton waste or wadding previously saturated with burning oil; then, by means of the air plunger provided on the oil container, to pump up gently a little pressure until the flame burns steadily and

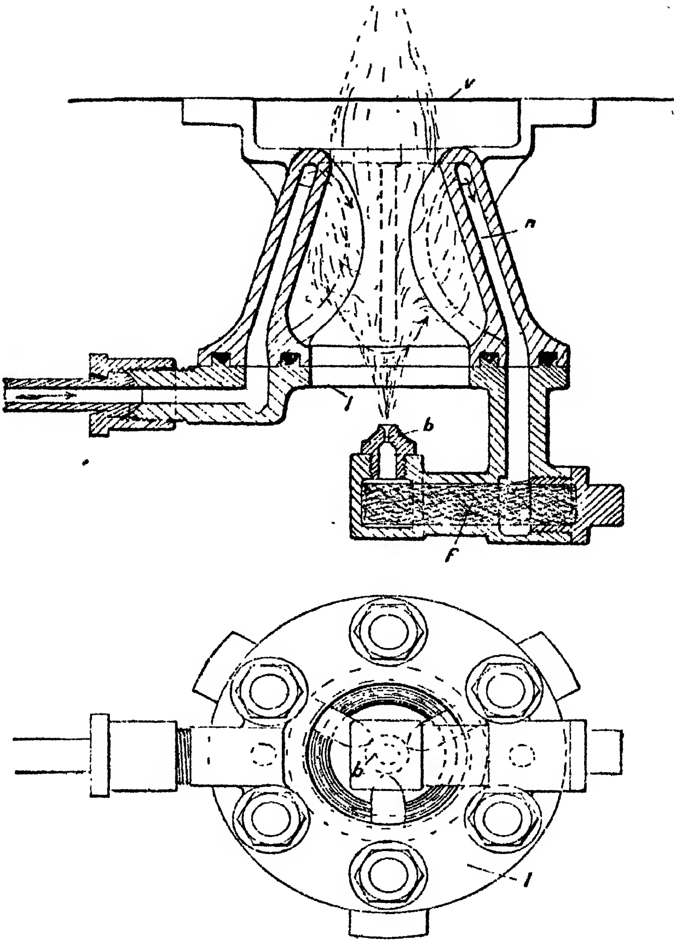


FIG. 140.—Butler vapour-jet burner.

blue at the base, when the lamp may be set to its work, and, after a further lapse of three minutes or so, the air pressure may be increased to suit. In this connection it is an advantage to use an oil container, having a large space for the air pumped in, so that the pressure may be maintained more equably against absorption and leakage.

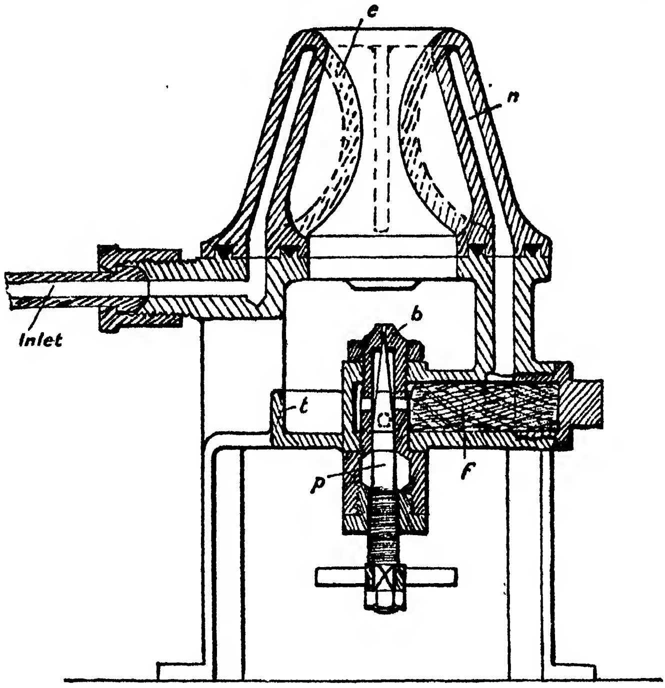


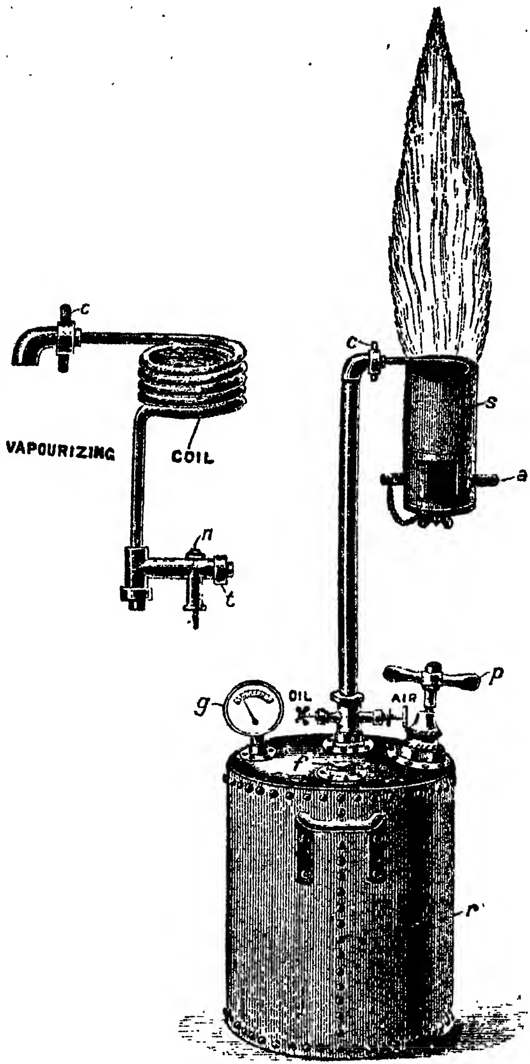
FIG. 141.—Butler jet burner with vapour regulator valve.

The best plan to adopt in extinguishing the flame is to free the air pressure, which effectually prevents spilling of oil, and escape of vapour after the flame has been put out. It is important in all jet burners to heat thoroughly the vaporiser before starting, and to use very little pressure until the flame burns blue.

The vapour jet or blow-lamp can also be adapted for

lighting, and is, for out-of-door purposes, specially suited for intermittent use, and is further extremely economical. Its great light-generating power may be judged when it is considered that a lamp weighing not more than 140 lbs., fully charged, and having a maximum height of 5 feet, is capable of producing a flame of some 1000 candle-power on a consumption of about half a gallon of oil per hour. A lamp of this size is illustrated by fig. 142, from which it will be seen that the vaporiser is a simple coil of steel pipe terminating at the burner placed some distance below the coil, and provided with a short branch carrying the nipple *n* and clearing plug *t*. The coil is encased in a tubular metallic shield *s*, and is provided with an opening for air, the extent of this opening determining the colour and luminosity of the flame. For instance, with the air shutter wide open, the flame burns blue and the lamp can be used for heating purposes, and when partly or wholly closed the colour of the flame is yellowish white, just sufficient air being admitted to prevent smoke. A strong point in favour of this lamp is the practice adopted for clearing the vaporiser coil by a blast of air from the container on shutting down; thus, instead of putting out the flame by allowing air to escape, as recommended for small blow-lamps, the burner supply pipe is fitted with an air-stop valve and an oil valve, the latter being closed to extinguish the flame, and the former opened, thus allowing a blast of air to blow out any solids deposited, this action being further expedited by first removing the plug *t*. No filtering medium is employed, but on the nipple exhibiting signs of choking, the oil is turned off for a moment and the air turned on, which process, in conjunction with the judicious handling of a suitable clearing prod, usually has the desired effect of freeing the nipple outlet.

It is important to maintain an equable pressure in the container (about 20 lbs. per square inch giving the best result), and to facilitate this being done, all lamps except the smallest sizes are provided with a pressure gauge, as shown at *g*. In regard to the starting of a lamp of this type, the same general directions should be followed as have already been given; emphasis is, however, laid on the advisability of thoroughly heating the coil before turning



. 142.—Sinclair self-cleansing Comet 1

on the oil, in order to minimise the escape of unburnt vapour. As above pointed out, all vaporisers are liable to get choked with continuous use; however, an effectual remedy for this is to heat the coil to dull redness, remove the plug *t*, then allow the coil to cool, tap the coil smartly all round with a hammer, and after this turn on a blast of air from the container, for which purpose the pressure may be a little higher than that required for working the lamp.

In the Wells blow-flame burner (fig. 143) the vaporiser *v* consists of a square casting in which are drilled a single

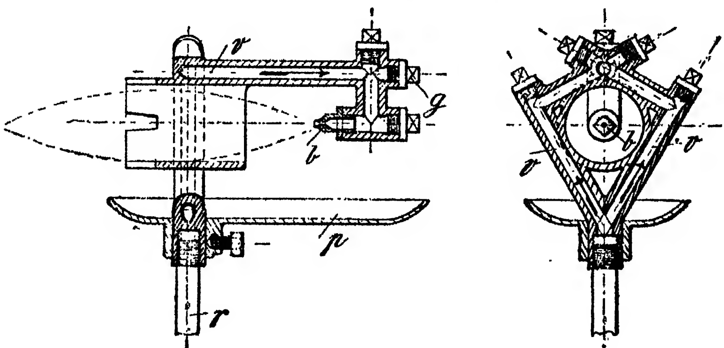


FIG. 143.—Wells kerosene blow-lamp arranged for heating.

or double series of holes for the passage of the oil or vapour, intercommunicating with each other so as to form a continuous ring. The advantage of this is the easy clearing of the vaporiser passages, when the plugs *g* are removed, thus obviating the necessity for disconnecting the vaporiser from the container. A blow-lamp has the advantage of being adapted for either lighting or heating, and of working at any inclination either upwards or downwards. The noise caused by the combustion of the high-velocity jet of superheated vapour can be materially modified by arranging a baffle over the flame or by the use of a diffuser chamber over the vapour jet, by which means the vapour and air can be distributed over a considerable area and be allowed to issue from a number of openings without

diminishing to any appreciable degree the heating value of the burner.

Blow-flame lamps are particularly useful for repair, or emergency work of all kinds; are proof against wind, rain, and rough handling; are entirely self-contained and very easily set to work; but are not suitable for permanent installations, where a steady light with quiet action is required. For these purposes incandescent or mantle lamps —ranging in power from 100 to 1000 c.p.—are extensively used for both indoor and outdoor lighting, where neither gas nor electric power is available, such as for street lighting in small towns, countryside railway stations, factories, and the like. Lamps of this kind are limited to the use of refined oils of either the kerosene or benzine series, of which the Kitson, Empire, Standard, Wells, and Helvetia are the best known; besides which mantle lamps are made to burn alcohol, of which the Stade lamp with inverted mantle is the most used.

The essential elements in the Kitson paraffin-oil mantle lamp[1]—for many years the only successful oil lamp using a mantle—are three, namely, the lamp (fig. 144), the oil reservoir and the tubing. The oil is kept in a special reservoir, of drawn seamless steel, fitted with a glass gauge to show the quantity of the oil in the tank, a pressure gauge, and a check valve for automatically cutting off the supply in the event of any damage being done to the pipes. The reservoir may either be immediately connected to the lamp, so as to make the whole arrangement self-contained, or it may be situated at some distance, the oil being forced along the pipes to the lamp by suitable air pressure.

The reservoir is filled one-third full of paraffin oil of a special variety, as it is essential to use a special quality of oil recommended for these lamps; inferior varieties lead to carbonisation and the deposit of soot, which is apt to choke up the burner. Air is forced into it by means of a small hand-pump until the gauge shows that a pressure of 55 lbs. to 75 lbs. per square inch has been obtained. Immediately below the pressure gauge there is a valve; when this is opened oil is allowed to flow into the tube

[1] *The Mechanical Engineer.*

attached to it, by which it is conveyed to the vaporising tube in the lamp. This is kept at a high temperature, and the vapour is ejected into the mixing cup and thence into the mixing tube. In passing in, it carries with it a sufficient amount of air to support combustion; thus the oil vapour and air become thoroughly mixed to form a highly combustible gas, which is led into the burners and brings them to a vivid incandescence.

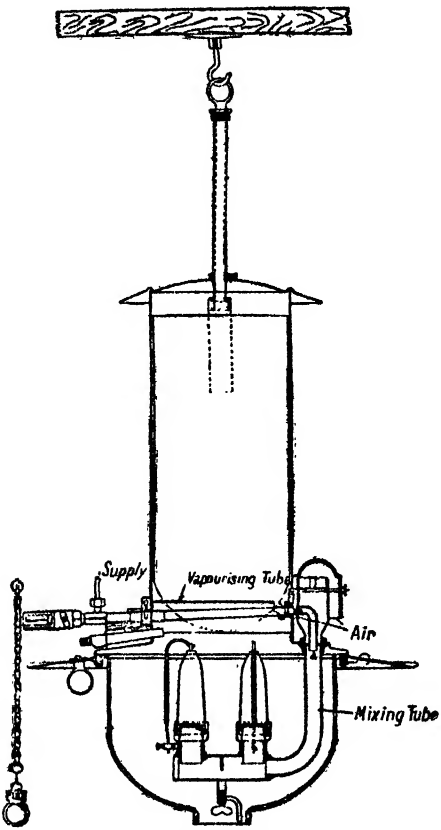


FIG. 144.—Diagram of Kitson vapour lamp for outdoor use.

Once the lamp has been started the vaporisation continues automatically, the being sufficient to keep the parts into which the oil is injected at the necessary temperature. It is, however, necessary to start the lamp by some preheating device, and there are three chief methods in use:—

(1) *Spirit Ignition.*—This is the simplest and most economical method when only a few lamps are installed. A small can is provided which contains the exact quantity of methylated spirit required, and this is poured into a cup fitted on the reflector, whence it passes down a tube into the burner

and is ignited by a match. The burning spirit heats up the vaporiser tube, and in about one minute this becomes sufficiently hot. The oil may then be turned on at the supply valve and becomes ignited, and the lamp should continue to work automatically.

(2) *Gas Ignition.*—When gas is available in a building, a Bunsen burner and pilot jet may be fitted under the vaporiser tube and connected with the gas mains. By pulling the chain, gas is turned on and ignited from the pilot, and in about one minute heats up the vaporiser sufficiently. As soon as the mantle becomes incandescent, the gas burner may be turned off, the gas consumed is therefore very little.

(3) *Electrical Ignition.*—This system is used in conjunction with petrol, and enables the lamp to be conveniently started from a distance. A switchboard is fixed to the wall in a suitable place, and on this is fitted an injector by which petrol is forced into the burner. An electric spark between two electrodes ignites the vapour. This spark is readily produced from a battery of dry cells and coil. The period of heating up in this case takes about 2 minutes.

The largest lamps give approximately 1000 c.p., and such a lamp with oil at 2s. per gallon will cost 3d. per hour.

But by far the most extensive application of paraffin for illuminating purposes is in the universal flat wick lamp; and in its improved form, with sleeve-wick burner stretched over a metal carrier, flame deflector disc, and especially annealed chimney, leaves little to be desired for the small country house when carefully trimmed and supplied with a highly refined deodorised oil; which remarks also apply to the Valor two- and three-burner, single reservoir, cooking-stoves as supplied by the Anglo-American Oil Co., these having a very practical form of index flame control with mica sight, asbestos lined chimneys, and burn steadily and long without smoke with just ordinary attention.

Quite a number of carburetted air-gas installations are in use in country houses, such being provided with generators known under various titles, as safety gas, aerogen, etc. The advantage of this gas is its adaptability for use in ordinary mantle burners; the generating apparatus, too, is simple, quiet, and automatic in action, and therefore well

adapted for the purposes named. In point of cost for installation, fuel, and upkeep, an air-gas plant compares well with an electric installation, especially where the number of lights does not exceed 30 to 100 or so; also with town gas lighting, where the cost per 1000 cubic feet is upwards of 5s., and petrol at 3s. per gallon.

About 1000 cubic feet can be made from 1 gallon of petrol of a special quality—which, by the way, should not exceed 700 specific gravity—and then forms a mixture which is non-explosive; if, however, the mixture is much richer than this, oil will condense in the pipes, and if much leaner will be explosive. The essential feature in the generating apparatus is the production of a saturated mixture of petrol and air, for which purpose such apparatus are generally arranged with a measuring pump, or its equivalent, for the petrol supply working in conjunction with a rotary or other form of positive action air pump; but as the volumetric displacement of the air impeller or forcer device is from 5000 to 6000 times greater than that of the petrol supply, it will be seen that it is important for these to be actuated in a regular and constant manner, under widely varying conditions. The necessary motive power for small plants is generally derived from a falling weight, and for large plants, either a hot-air or water motor. The simplest form of air-gas generator, and one that may be actuated without a motor of any kind, consists of an air chamber, a carburetting chamber, and a settling chamber; in such an apparatus the required saturation degree can be determined by a bye-pass between the first and second chambers, and the quantity of gas generated by the inflow of water to the air chamber from an ordinary house cistern.

In closing this chapter mention must also be made of the Mansfield oil-gas producer, the object of which is to place in the hands of scientists whose laboratories are often removed from the advantages of a supply of town's coal gas a complete plant of great durability and simplicity, by which can be made a constant supply of gas from any kind of oil, mineral, animal, or vegetable. 1000 cubic feet of oil gas, which is the equivalent of about 3000 cubic feet of average coal gas, requires from 10 to 12 gallons of solar

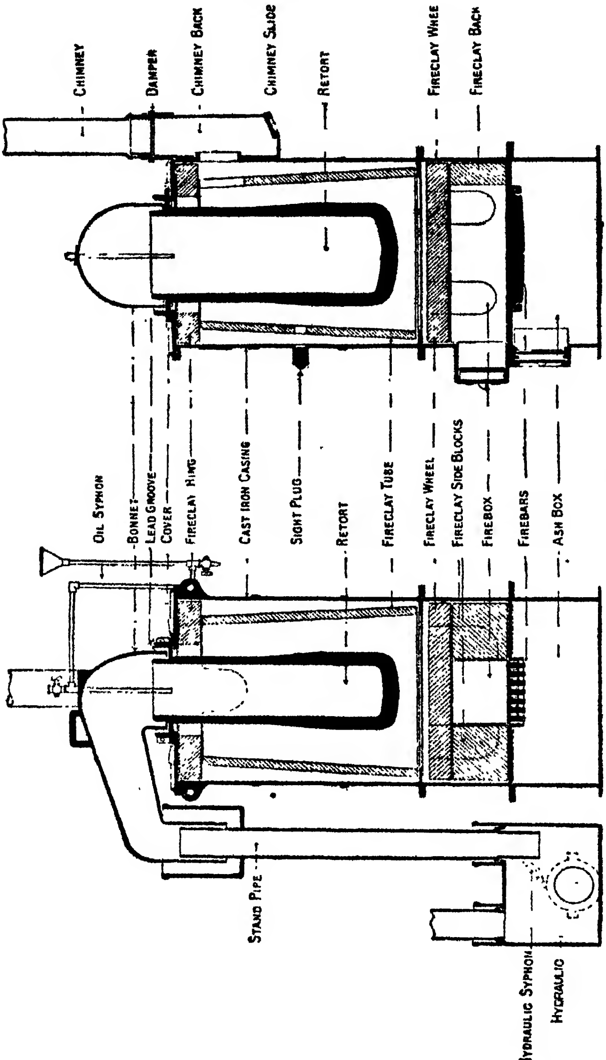


FIG. 145.—Sections showing the Mansfield oil-gas generator.

oil plus 2 cwts. of coal, and will cost about 10s. with oil at 1s. per gallon and coal at 2s. per cwt.; add to which 2s. per thousand for retort and fireclay renewals, brings the total cost to 12s., which is then the equivalent of coal-gas at 4s. per thousand.

The generator, as shown in fig. 145, operates on the retort system; oil, which may be of any kind, refined, semi-refined, or residual, is supplied to the retort by a syphon and is immediately converted into gas, which rises into the bonnet, and thence down the stand-pipe to the hydraulic seal, whence it passes on to a gas-holder. In starting up, a fire is first lighted, and a steady heat maintained until the retort is heated to redness; around the top of this is an annular recess into which the bonnet rests, and around the top of the downtake another recess for the other end of the bonnet; that over the retort is partly filled with lead, and that over the downtake with water, thus forming a seal at both ends. The gas thus produced is absolutely fixed and can be piped to any distance.

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